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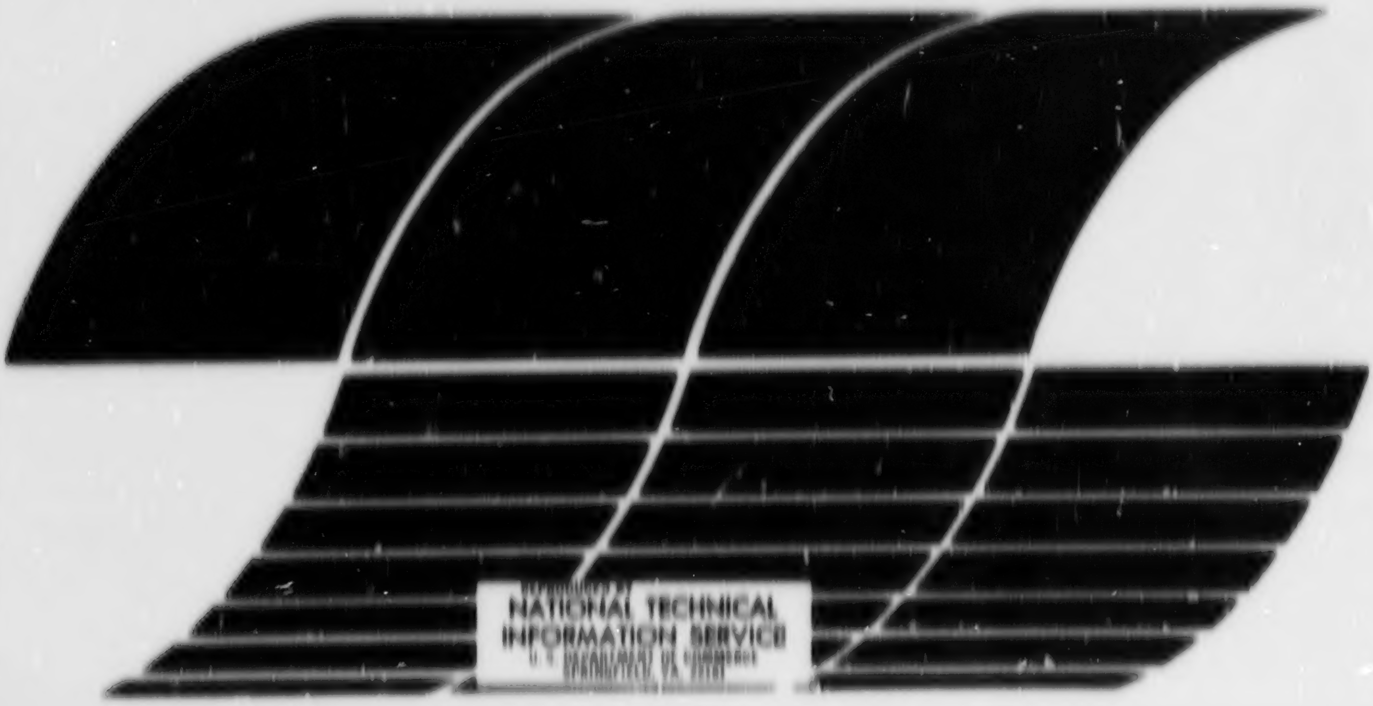

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Energy from the West

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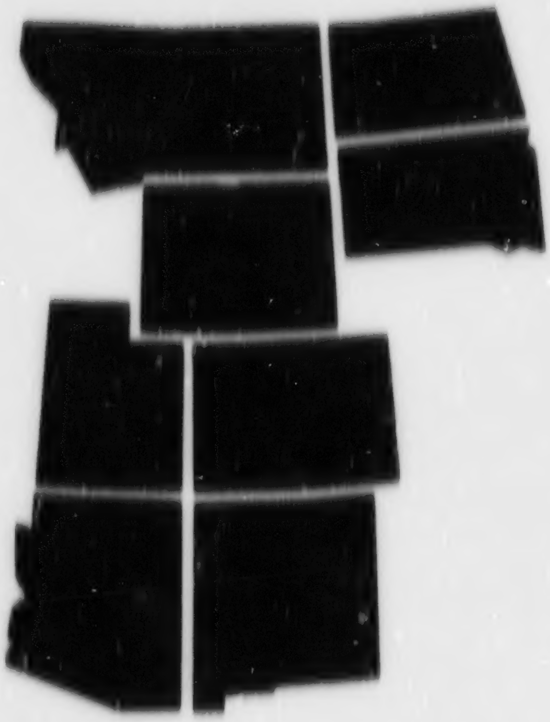
Volume IV Appendices



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FOREWORD

The production of electricity and fossil fuels inevitably creates adverse impacts on Man and his environment. The nature of these impacts must be thoroughly understood if balanced judgements concerning future energy development in the United States are to be made. The Office of Energy, Minerals and Industry (OEMI), in its role as coordinator of the Federal Energy/Environment Research and Development Program, is responsible for producing the information on health and ecological effects - and methods for mitigating the adverse effects - that is critical to developing the Nation's environmental and energy policy. OEMI's Integrated Assessment Program combines the results of research projects within the Energy/Environment Program with research on the socioeconomic and political/institutional aspects of energy development, and conducts policy - oriented studies to identify the tradeoffs among alternative energy technologies, development patterns, and impact mitigation measures.

The Integrated Assessment Program has utilized the methodology of Technology Assessment (TA) in fulfilling its mission. The Program is currently sponsoring a number of TA's which explore the impact of future energy development on both a nationwide and a regional scale. For instance, the Program is conducting national assessments of future development of the electric utility industry and of advanced coal technologies (such as fluidized bed combustion). Also, the Program is conducting assessments concerned with multiple-resource development in three "energy resource areas":

- Western coal states
- Lower Ohio River Basin
- Appalachia

This report describes the results of the first phase of the Western assessment. This phase assessed the impacts associated with three levels of energy development in the West. The concluding phase of the assessment will attempt to identify and evaluate ways of mitigating the adverse impacts and enhancing the benefits of future development.

The report is divided into an executive summary and four volumes:

- I Summary Report
- II Detailed Analyses and Supporting Materials
- III Preliminary Policy Analysis
- IV Appendices

Stephen J. Gage
Deputy Assistant Administrator
for Energy, Minerals, and Industry

ABSTRACT

This is a progress report of a three year technology assessment of the development of six energy resources (coal, geothermal, natural gas, oil, oil shale, and uranium) in eight western states (Arizona, Colorado, Montana, New Mexico, North Dakota, South Dakota, Utah, and Wyoming) during the period from the present to the year 2000. Volume I describes the purpose and conduct of the study, summarizes the results of the analyses conducted during the first year, and outlines plans for the remainder of the project. In Volume II, more detailed analytical results are presented. Six chapters report on the analysis of the likely impacts of deploying typical energy resource development technologies at sites representative of the kinds of conditions likely to be encountered in the eight-state study area. A seventh chapter focuses on the impacts likely to occur if western energy resources are developed at three different levels from the present to the year 2000. The two chapters in Volume III describe the political and institutional context of policymaking for western energy resource development and present a more detailed discussion of selected problems and issues. The Fourth Volume presents two appendices, on air quality modeling and energy transportation costs.

READER'S GUIDE

This report is divided into four volumes. In addition, an executive summary provides a brief description of the major research results of this western assessment.

Readers interested in a general description of the assessment results should read Volume I. Chapters I and II describe the context and methodological framework of the assessment. Chapter 3 provides a summary description of the impact analysis, e.g., water and air impacts, population changes, etc. Chapter 4 summarizes some policy implications of these results, although the assessment is still in the early stages of policy analysis at this time. Chapter 5 briefly describes what the reader can expect from the second phase of the project.

Readers interested in particular geographical areas might be interested in one or more of the six site-specific chapters (Chapters 6-11) of Volume II which describe in detail results pertaining to the following areas: Kaiparowits/Escalante, Utah; Navajo/Farmington, New Mexico; Rifle, Colorado; Gillette, Wyoming; Colstrip, Montana; and Beulah, North Dakota. Readers interested in site-specific air, water, socio-economic and ecological impacts will find these discussed in subsections 2, 3, 4, and 5, respectively, of each chapter in this volume. Chapter 12 in volume II describes the results of the regional analyses. This chapter should be particularly valuable to readers interested in transportation, health, noise and aesthetic impacts, which are not discussed in the site-specific chapters, and subjects (such as water availability) which tend to be regional rather than site-specific in nature.

Volume III represents a first step in the identification, evaluation and comparison of alternative policies and implementation strategies. Chapter 13 presents a general overview of the energy policy system. Chapter 14 identifies and defines some of the principal problems and issues that public policymakers will probably be called on to resolve. The categories of problems and issues discussed are: water availability and quality, reclamation, air quality, growth management, housing, community facilities and services, and Indians.

Volume IV provides two technical appendices:

- a discussion of alternative approaches to modeling air quality in areas with complex terrain
- cost comparisons of unit trains, slurry pipelines and EHV transmission lines

APPENDIX A

TECHNICAL NOTE

AN INVESTIGATION OF COMPLEX TERRAIN MODELING APPROACHES USING THE STEADY-STATE GAUSSIAN DISPERSION MODEL

(Prepared by Radian Corporation
Austin, Texas, September 3, 1976)

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SECTION 1

INTRODUCTION

The development and application of atmospheric dispersion models which accurately treat the interaction of elevated plumes with complex terrain is an area of increasing importance. Emerging areas of concern such as the development of energy resources in areas of irregular and elevated terrain (e.g., the Rocky Mountain-Great Basin Region) require an accurate treatment of plume/terrain interaction.

It is recognized that a number of problems are encountered in applying steady-state Gaussian dispersion models to areas of elevated, rugged terrain, which are not encountered in flat terrain modeling. It is further recognized that modeling treatments suitable for one site might not be suitable for another site because of the great degree of variability in the topography and local dispersion meteorology among sites.

These modeling concerns include but are not limited to:

1. the effects of increased surface roughness on rates of diffusion,
2. the potential for impaction of elevated plumes against elevated terrain and the effects of atmospheric stability on this potential for impaction,
3. the effects of gently-sloping terrain on ground-level pollutant concentrations,
4. the treatment of ground-level reflection of dispersion plumes in areas of complex terrain,
5. the effects of local drainage flows on the potential for impaction of low-level releases against elevated terrain,
6. the relative accuracy of finite-difference type models versus steady-state Gaussian models for complex terrain modeling.

As part of the modeling effort for the Technology Assessment (T.A.) of Western Energy Resources Development, Radian has examined some of these modeling concerns and has found certain complex terrain modeling options for steady-state Gaussian dispersion equations to be more satisfactory than others for specific applications. In these examinations of complex terrain/dispersion interactions an extensive literature search was conducted. Where possible, dispersion predictions were made using different model treatments and were compared to available measured data in an attempt to establish the validity of the different treatments. In the following section, some of the previously mentioned areas of modeling concern are examined. Conclusions drawn from the literature search and the results of model treatment verification exercises are described.

SECTION II
INVESTIGATION RESULTS

A number of researchers conclude that the roughness of the ground surface at complex terrain sites enhances both horizontal and vertical diffusion due to the generation of greater turbulence as the air passes over the surface. After reviewing a number of diffusion experiments in areas of complex terrain, Bruce Egan of Environmental Research and Technology states[1]:

> "A pervasive conclusion of the various experiments is that the rates of dilution of plumes in complex terrain are larger than those which would be predicted over level terrain for the atmospheric stability classifications indicated by the meteorological observations."

The measure of the degree of turbulence generated by the wind passing over the rough terrain is reflected in the dispersion coefficients or "sigmas" in the Gaussian dispersion equation. Two sets of sigmas were examined to determine which set would be most applicable to the complex terrain regions under examination in the T.A.

The first set of sigmas was developed as a result of a diffusion investigation conducted at Colstrip, Montana by the Department of Earth Sciences at Montana State University[2]. The purpose of this study was to estimate the effects of rugged terrain on the dispersion of a plume from an elevated source. A silver iodide plume released continuously from an effective height of 500 feet above the general terrain was selected as the tracer.

---

[1] Egan, B.A., "Turbulent Diffusion in Complex Terrain", Lectures on Air Pollution and Environmental Impact Analysis, American Meteorological Society, September 29-October 3, 1975.

[2] Heimbach, J. A., A. B. Super, and J. T. McPartland, "Dispersion from an Elevated Source over Colstrip, Montana", Section 26, Field Monitoring Programs, 68th Annual Meeting of the Air Pollution Control Association, Boston, Massachusetts, June, 1975.

Although values of σ_y and σ_z were derived from data taken in a region of rugged terrain, these dispersion coefficients were not selected for use by Radian in the atmospheric modeling effort of the T.A. Log-log plots of vertical dispersion coefficients as a function of downwind distance show that the values of σ_z increase in much the same manner as Turner's sigmas out to a distance of about 2-3 Km. Beyond this point, the value of σ_z "levels off" with distance. Since maximum pollutant concentrations from large elevated sources normally occur at distances greater than 2-3 Km from the source, the accuracy of the "Colstrip" sigmas in the "leveled off" region is of primary interest. However, the Colstrip concentration data used to produce the curves of σ_z versus downwind distance do not justify the "leveling off" of the curves. In addition, the "Colstrip" vertical diffusion coefficients (σ_z's) for Stability Classes A, B, C and D are lower than corresponding values of Turner's dispersion coefficients beyond a transition region of about .8-8 Km. The lower values at these distances do not reflect the phenomenon of increased turbulence over rugged terrain which the "Colstrip" vertical sigmas would be expected to depict. For these reasons the "Colstrip" dispersion coefficients were not selected.

Dispersion coefficients described by Turner are the most widely used and accepted dispersion coefficients for atmospheric dispersion equations. These sigmas were originally developed by Gifford[7] from diffusion experiments conducted by Hay and Pasquill[8] over gently rolling, open terrain.

The accuracy of the Turner dispersion coefficients for areas of complex, rugged terrain was tested by comparing them to crosswind plume standard deviations measured in the vicinity of the Navajo Generating Station in extreme Northern Arizona. During 1974 and 1975, a full-scale dispersion study was conducted by Rockwell International and its subcontractors at this power plant to determine the need for sulfur dioxide removal. As part of this study, the horizontal crosswind standard deviation of SO_2 concentration (σ_y) was measured on several days at different downwind distances from the source. A total of 18 values of σ_y measured on six days were compared to corresponding values of Turner's horizontal crosswind dispersion coefficients (σ_y) for the same downwind distance and stability category (Table II-1). This comparison showed that the measured σ_y's were, on the average, only 8.5% greater than the

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[7] Gifford, F. A., Jr., "Use of Routine Meteorological Observations from Estimating Atmospheric Dispersion", Nuclear Safety, 2(4): 47-51, 1961.

[8] Pasquill, F., Atmospheric Diffusion, D. Van Nostrand Co., Ltd., London, 1962.

TABLE II-1

COMPARISON OF OBSERVED AND THEORETICAL PLUME HORIZONTAL CROSSWIND STANDARD DEVIATIONS (σ_y) - NAVAJO POWER PLANT

Date	Time	Downwind Dist.	Observed σ_y	Turner's Theoretical σ_y*	Colstrip Theoretical σ_y*
10-16	1131 MST	24	1025m	880	1000
	1120	16	1190	620	700
	1242	6	280	260	290
11-24	0842	10	165	410	550
	0907	24	970	880	1000
	1136	3	155	140	240
	1210	8	390	340	470
	1301	27	635	980	1010
12-2	0907	3	250	140	740
	1025	19	470	730	860
	1114	24	1125	880	1000
12-10	0845	3	140	140	240
	1017	8	435	340	476
	1113	14	425	550	650
	1222	28	460	1000	1100
1-3	0925	3	330	140	240
	1207	3	145	140	240
1-29	1018	27	410	980	1100

*For E Stability.

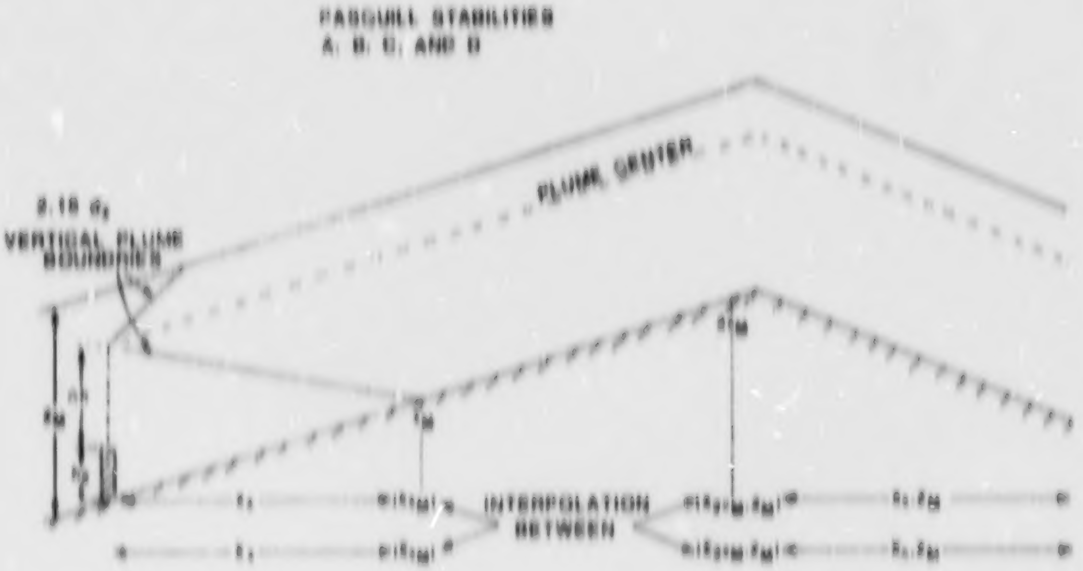
PASQUILL STABILITIES
A, B, C, AND D
2.15 σ_z
VERTICAL PLUME BOUNDARIES
PLUME CENTER
INTERPOLATION
BETWEEN

FIGURE II-1. NOAA MODEL PLUME/TERRAIN INTERACTION FOR UNSTABLE AND NUETRAL CONDITIONS

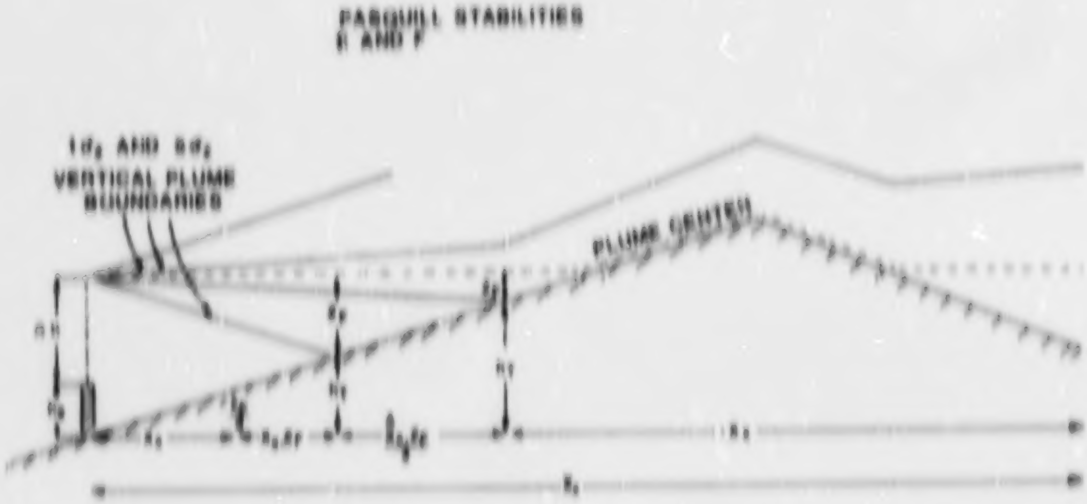
PASQUILL STABILITIES
E AND F
1σz AND 2σz
VERTICAL PLUME
BOUNDARIES
PLUME CENTER

FIGURE II-2. NOAA MODEL PLUME/TERRAIN INTERACTION FOR STABLE CONDITIONS

values given by Turner. They were, however, 22% lower on the average, than corresponding values obtained from the Colstrip study.

Based on the limited results of this analysis, it appears that Turner's dispersion coefficients may, in some instances, be suitable for making dispersion estimates in areas of rugged terrain, although they may slightly underpredict the horizontal crosswind plume spread. For this reason, and because of their general acceptability and applicability to flat terrain modeling, Turner's dispersion coefficients were selected for general use in the air impact analysis of the T.A.

There are several modeling approaches for treating the interaction of dispersing plumes with elevated terrain. Three steady-state Gaussian models which attempt to account for this phenomenon were examined: the NOAA Model[5], the EPA VALLEY Model[6], and Model CDM[7].

In the NOAA Model, the plume is assumed to remain at a fixed height above the terrain for neutral and unstable stability categories. During stable conditions, the plume centerline is assumed to remain at a fixed height above the source. When the terrain height exceeds the level of the plume centerline, the centerline concentration is then assumed to apply (Figures II-1 and II-2).

The EPA VALLEY Model assumes that the plume centerline remains at a fixed height above the terrain for neutral and unstable categories. During stable conditions, the plume centerline is assumed to remain at a fixed height above the source; however, the plume centerline must always be ≥10 meters above the level of the terrain. If the receptor height is greater than 10m above the plume centerline, calculated concentrations for the receptor height are reduced linearly, such that for a receptor 400m above plume centerline, the receptor concentration is 0. The model doesn't look back along the plume to determine whether or not it has encountered terrain. Hence, it treats receptors on leeward slopes in the same manner as on windward slopes (Figure II-3).

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[5] Van der Hoven, Isaac, et al., Southwest Energy Study, Appendix E - Meteorology, NOAA, March, 1972.

[6] Burt, Edward W., Description of Terrain Model C8M3D, U. S. Environmental Protection Agency, Personal Communication, August 14, 1975.

[7] Environmental Research and Technology, Description of Gaussian Dispersion and Plume Rise Models, November 19, 1974.

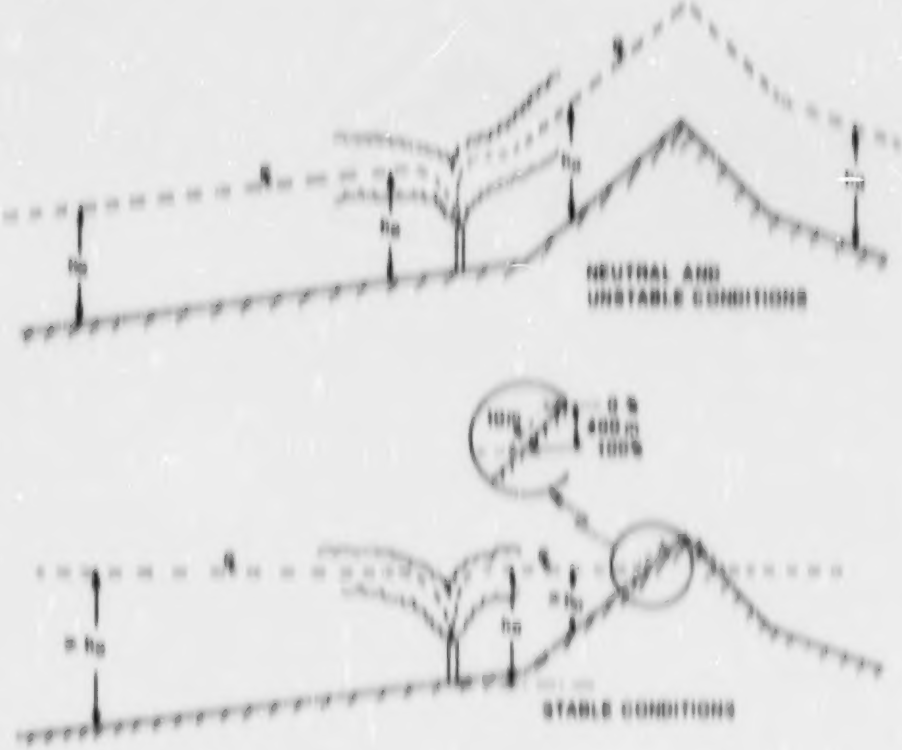
hp
hp
hp
hp
NEUTRAL AND
UNSTABLE CONDITIONS
10%
0.5
400 m
100%
≈ hp
hp
≈ hp
STABLE CONDITIONS

FIGURE II-5. EPA VALLEY MODEL PLUME/
TERRAIN INTERACTION

The PSDM, developed by Environmental Research and Technology, accounts for terrain interaction by permitting the plume to be lifted one-half of the difference between the height of the receptor (the point on the ground for which the concentration is being computed) and the height of the stack base, with the additional restriction that the plume shall always be at least half of its calculated equilibrium height above the ground. This terrain treatment applies for all stability categories (Figure II-4).

Each of these three models assume that reflections occur at the level of the elevated receptor plume. INTERA Environmental Consultants[5] compared measured tracer concentrations to predictions made using the INTERA (non-Gaussian) and the EPA VALLEY and the NOAA models for the region of complex terrain of Huntington Canyon, Utah. As a result of this study, it was concluded that the EPA VALLEY and NOAA models tended, in general, to overpredict the measured concentrations in the Huntington Canyon area.

In an attempt to further verify the validity of these models, Radian compared measurements made in the vicinity of the Navajo Generating Station[6] with NOAA model predictions. Measured ground-level pollutant concentrations resulting from impaction of the Navajo plume during stable dispersion conditions against a cliff located approximately 20-25 Km from the plant were compared to NOAA model predictions. This comparison showed that the model estimates were about a factor of two too high.

Radian suspected that the tendency for these models to overpredict concentrations in areas of complex terrain was a result of the reflection assumption incorporated in the models. In an attempt to overcome this problem, the NOAA model terrain treatment was modified such that ground-level reflections were calculated to occur at the plant grade or the elevation of the base of the emission source in contrast to the original NOAA model assumption of reflections from the elevated terrain surface. It was believed that this model treatment would more accurately account for the physical process of the reflection

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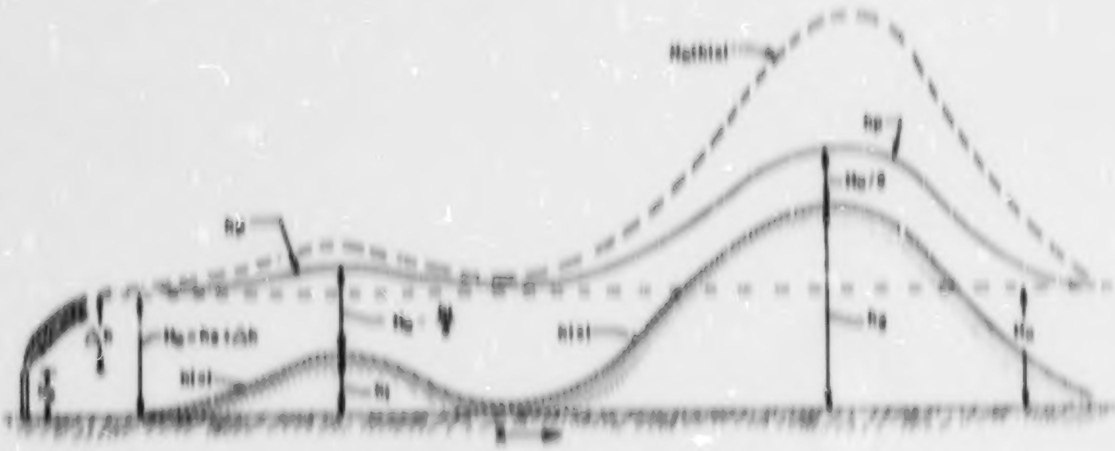
[5] Lantz, R. B., and G. F. Hoffnagle, "A Comparison of Plume Dispersion Calculations with Tracer Measurements at Huntington Canyon, Utah", presented at 68th Annual Meeting of the Air Pollution Control Association, June 15-20, 1975, Boston, Massachusetts.

[6] Navajo Generating Station, Sulfur Dioxide Field Monitoring Program, Vols. I, II, III, and IV, Air Monitoring Center - Rockwell Int., Meteorology Research, Inc., System Applications, Inc., September, 1976.


$H_0 + h(x)$
h_p
h_p
Δh
$H_0 = h_s + \Delta h$
$h(x)$
$h(x)$
h_s
x

h_s is physical stack height
Δh is plume rise
H_0 is effective stack height (physical stack height plus plume rise)
$h(x)$ is terrain height above stack base elevation
h_p is plume centerline height above stack base elevation

Figure II-4

PSDM Model Plume/Terrain Interaction

of the lower portion of the plume from an elevated terrain surface, because it would recognize that pollutants reaching ground-level during stable dispersion conditions would not continue to travel uphill in the direction of the overlying plume centerline. Instead, these ground-level pollutants would become entrained into existing stable drainage flows and separated from the main body of the plume. By incorporating this terrain treatment, reflections are treated in the manner described by Turner[16] for flat terrain situations, but the concentrations from reflected pollutants are minimized during periods of stable plume dispersion in elevated terrain. In addition, the minimum 10m separation distance between the plume centerline and the receptor as used in the EPA VALLEY model was used by Radian in the T.A. air impact assessment.

Model predictions using this terrain treatment were compared to measured concentrations along the tops of cliffs in the vicinity of the Navajo Generating Station for periods of plume impingement. For these periods, model predictions showed very good agreement with measured values for both peak and one-hour averaging periods; that is, model predictions were within ±16 percent of measured values.

Examination of Navajo field study data supported the assumption in the NOAA and EPA models that in cases of plume dispersion over elevated terrain, stable plumes generally disperse at a constant level above the plant grade or base elevation of the source. The plume configuration assumptions incorporated into model PSDM were not supported. Plume observations indicated that this common assumption of the NOAA and EPA VALLEY models applies to both abrupt and gentle changes in terrain features beneath the dispersing plume. Therefore, this assumption, in addition to the modified reflection assumption, was incorporated into the dispersion models exercised for the T.A.

The accuracy of the terrain model treatment for situations of plume dispersion over gentle upward sloping terrain was tested by comparing model predictions to measured concentrations in the Navajo Generating Station area. On the day examined, the plume was traveling over terrain that sloped upward at a rate of about 26m per Km. At the elevated end of this gentle slope (approximately 22 Km from the plant), and at a level approximately 580m above plant grade, a peak concentration of 238 $\mu g/m^3$ was monitored. At this time, the plume centerline was in the vicinity of the monitor. Although the plume centerline was at ground level at this distance, the horizontal separation between the plume and the monitor was not known.

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[16] Turner, D. Bruce, *Workbook of Atmospheric Dispersion Estimates*, U. S. Environmental Protection Agency, Office of Air Programs, Publication No. AP-26.

Model predictions for the downwind distance and receptor height corresponding to this monitor show a peak plume centerline concentration of 452 $\mu g/m^3$. However, examination of these predicted results show that at horizontal distances of one standard deviation either side of the plume centerline, the predicted concentration drops to 273 $\mu g/m^3$, or approximately the peak value measured at the monitor. Since the horizontal location of the plume centerline with respect to the monitor was not precisely observed in the Navajo study, the predicted value may be accurate. Assumption of flat terrain beneath the plume results in a predicted value of almost zero and the assumption of reflections from a plane at the level of the receptor results in predicted concentrations almost twice the 452 $\mu g/m^3$ level.

SECTION III

CONCLUSIONS

The following general conclusions can be drawn from this investigation of complex terrain modeling.

- Pasquill-Gifford dispersion coefficients may accurately describe the plume spread in some complex terrain situations.
- Observations show that elevated plume centerlines generally parallel the underlying terrain surface during unstable and neutral conditions.
- Plumes may impact abruptly-rising elevated terrain during stable conditions.
- During stable conditions the effective height of the plume above gently upward-sloping terrain may be decreased. As a result, measured concentrations at downwind (uphill) receptors may be higher than flat terrain modeling results would indicate.
- Concentration predictions for plume impaction on abruptly-rising terrain may be too high if the NOAA and EPA VALLEY models are used.
- Concentration predictions for plume impaction on abruptly-rising and gently sloping terrain are close to measured values for the complex terrain situations examined, if Radian's Gaussian dispersion model, modified to minimize the effect of ground-level reflections, is used.
- The findings resulting from this literature search and from these comparisons of model predictions and measured data do not negate the use of alternate complex terrain modeling approaches for other combinations of terrain, local meteorology, and plant configurations. Furthermore, although the terrain modeling approach selected for use by Radian in the T.A. provides accurate

predictions for the test cases examined, it may not be valid for use in certain other situations.

SECTION IV

REFERENCES

Listed below are a number of recent articles treating the subject of complex terrain modeling. These references were not sited in this Technical Note.

Atmospheric Dispersion of Airborne Effluents from The Roan Plateau, Battelle Pacific Northwest Laboratories, October 1973.

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APPENDIX B

ROUTE SPECIFIC COST COMPARISONS: UNIT TRAINS, COAL SLURRY PIPELINES AND EXTRA HIGH VOLTAGE TRANSMISSION

by

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DISCLAIMER

The work performed in this study is the responsibility of the authors. The views, findings, recommendations and opinions expressed do not necessarily reflect those of the U.S. Environmental Protection Agency, The Science and Public Policy Program of the University of Oklahoma, or the University of Illinois.

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SECTION I

INTRODUCTION

1.1 Problem Statement

The comparative economics of three modes of coal-energy transport are studied. These include: unit trains, coal slurry pipelines and extra high voltage (EHV) transmission from mine mouth generating plants. The basis for comparison is cost rather than price. To facilitate the use of the data, costs are presented on the following bases: cents/ton-mile, dollars/ton, cents/MMBtu transported, and cents/MMBtu-mile.

For each mode of transport, a generalized statement of components, component costs and parameters is presented. From this, route specific analyses are developed. These are based on the movement of 25 million tons of coal per year except for electric transmission which is based on an input of 3000 MW. It should be noted, however, that 25 million tons per year may imply a possible input of almost 5000 MW at the supply end. The following routes are analyzed:

(1) Farmington, New Mexico to Los Angeles, California
    a. Unit trains.
    b. Coal slurry pipeline.
    c. EHV transmission (3000 MW)

(2) Gillete, Wyoming to Chicago, Illinois
    a. Unit trains.
    b. Coal slurry pipeline.
    c. EHV transmission (3000 MW)

(3) Gillete, Wyoming to Houston, Texar
    a. Unit trains.
    b. Coal slurry pipeline.

(4) Colstrip, Montana to Houston, Texas
    a. Unit train.

(5) Colstrip, Montana to Seattle, Washington
    a. Unit trains.
    b. Coal slurry pipeline.

(6) Electric transmission, EHV transmission (3000 MW)
    a. Kaiparowits, Utah to Los Angeles, California.
    b. Beulah, North Dakota to Chicago, Illinois.
    c. Colstrip, Montana to Chicago, Illinois.

Coal transport from Gillette, Wyoming to New York City via unit trains has been excluded from the detailed analysis. This is based on a number of factors. First, the state of the tracks east of Chicago are considerably more deteriorated than those further west. The cost of rebuilding to accomodate the shipments would be very much higher than our estimates for western roads. While rehabilitation would affect all rail transport, the cost basis would be added to the unit train movement east of Chicago. Therefore, the western roads cite a lack of cooperation in rate making and joint shipment possibilities as one moves east. The problem appears to be who would get what part of the joint rate and how high would it be. Second, the population density moving east rapidly increases. There is little room for the rerouting of right of way to avoid noise and surface traffic problems. This may render the exercise improbable. Rail traffic densities in the east only exacerbate the problem. A general cost estimate for this route has been provided assuming a route through northern Indiana and Ohio, the northwest corner of Pennsylvania, southern New York to a point east of the Appalachians, then southeast through Pennsylvania and east across New Jersey to New York City. An alternative would be from about Buffalo to the Hudson River and then south on the east bank to New York City.

Because Case 5 anticipates coal export as well as local usage, no provision for evaporating or dumping coal slurry water after dewatering has been made. Therefore, the analysis includes the costs of returning the water to the point of origin. This reduces the water requirement, after the first line fill, to make-up water. The specific routes and transport modes are shown in Figure 1.1. An abbreviated parameter format is presented in Table 1.1.

The remainder of this introduction is devoted to the background of each mode. This will provide an understanding of the system under consideration, the current controversies, and the non-cost items which have been included.

1.2 Unit Trains

A unit train is a single purpose dedicated, integrated train for hauling one commodity, in this case coal. It is composed of special purpose cars which haul continuously from mine to consumer. Due to different definitions of the term "unit train," it is difficult to say exactly what percentage of rail coal moves by this method; estimates for 1972 vary from one-third to one-half of total coal rail traffic [1]. Given current technology and forecast consumer demand, unit trains will become even more important for hauling projected high volume coal shipments.

Unit trains were first used in 1957, when the Reserve Mining Company transported iron ore over a 50-mile private section of track to a processing plant at Silver Bay, Minnesota [2]. Utilization of the unit train for carrying coal first became prominent in the mid-1960's. The unit coal train concept was refined in the late 1960's. Further improvements have been made since then. From the very beginning, its successful initiation has almost always depended upon close cooperation between the mining company, the railroad, and an electric utility company. Typically, long term contracts, sometimes of ten years or more, are made so that large capital investments for equipment can be justified. This includes the

Figure 1.1

Route Analysis

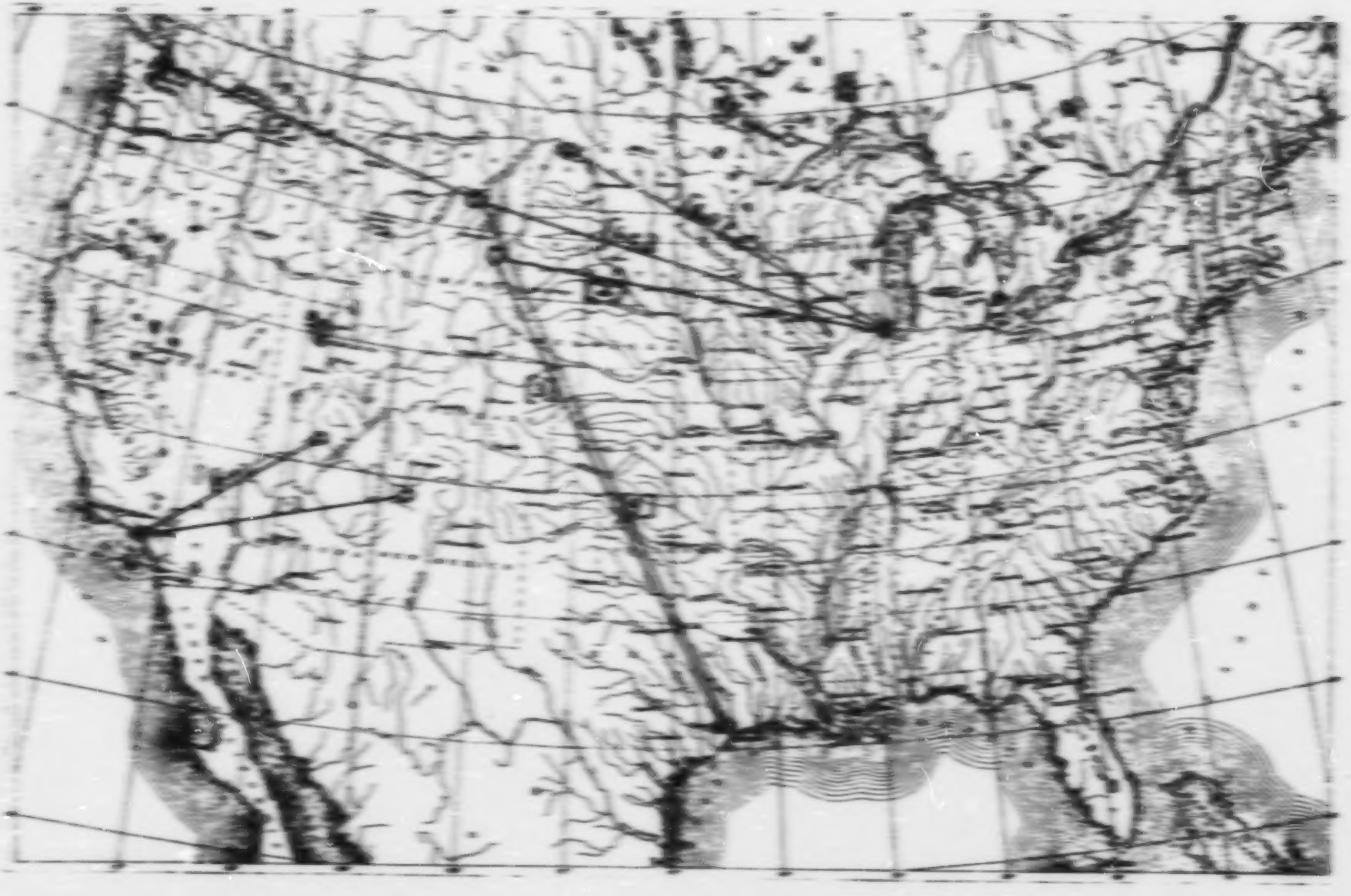

Table 1.1 Parameters for Coal Transport System

Supply Point	Transport Facility	Receiving Point
Primary Parameters		
Tons/Day	Tons/Day and Distance	Tons/Day
Common to All:		
1. Mine	1. Terrain	1. Utilization
2. Loader	2. Labor	2. Labor
3. Storage	3. Power and Fuel	
4. Labor		
Railroad:	(Speed)	
5. Loading Facility	4. Rails	3. Unloading Facility
6. Supplies	5. Locomotives	4. Storage
	6. Cars	5. Pulverizing in Power Plants
	7. Stations	
Slurry Pipeline:	(Flow Velocity)	
5. Slurry Preparation Mills Storage Tanks Agitators	4. Pipeline	3. Stirred Storage
6. Pumping	5. Pumping Stations	4. Separation Facility to Centrifuge Coal and Water, Water Disposal
7. Water Supply	6. Supplies	
8. Supplies		
EHV Transmission:		
5. Voltage Step-up	4. Transmission Lines and Towers	3. Voltage Conditioning and Distribution
6. Rectification		

unit train itself as well as coal handling facilities at both ends of the haul. It should be noted, however, that the long term contracts do not extend to unit train rates. These must be set annually. Early operations were typified by railroad owned coal cars and locomotives, primarily because they already owned the equipment. When freight cars specifically suited to coal hauling and larger locomotives became the rule rather than the exception, it often became preferrable for the utility companies to own their own trains, both as part of their investment and to insure continuity of delivery in times of car shortages. However, all train crews and most maintenance are provided by the railroads. Traditionally, mining companies have been more hesitant to assume unit train ownership, probably because they have less to gain than either the utility companies or the railroads. However, the associated contracts do provide a guaranteed scheduled outlet for the mine's coal which may lower costs. Furthermore unit trains often lower the delivered cost of coal sufficiently to encourage increased coal usage. For the railroads, unit trains provide better equipment and plant utilization than do other rail modes. For the coal burning utility companies, they lower fuel expenditures and establish a stable fuel supply [1]. Schedule receipts also lower inventory costs. Lowering transport costs, by increasing the net-back at the mine, increases economically recoverable coal reserves; mines may go deeper, recovery percentages may increase and the time before mine closure may be effectively prolonged.

A unit train operation involves much more than merely the locomotive and hopper cars to haul the coal. Successful operation is dependent upon concentrated usage of equipment so that the train spends as much time as possible on the road. To do this, high rate loading and unloading facilities as well as significant storage capability must be installed to supplement the train. These improved coal handling facilities must be included in the total economic and technological analysis of the unit train. The increased costs due to this additional equipment and handling are, however, less than those incurred in the movement of similar but fragmented tonnages picked up and delivered to and from several locations in multiple car lots. This follows from the increased efficiency and load factor associated with a unit train. With one cargo, one origin, one destination, often no stopping even for loading or unloading, and no yard time or train make-up time, instead of averaging 60 miles per day, these trains may average over 800 miles per day. However, this is highly dependent upon track conditions.

The cost of building and/or maintaining a railroad must also be factored into unit train costs. Because of declining revenues (due to the loss of other revenue producing freight haulage) and the diversification of some railroads, many roads have spent a minimum on track and right of way maintenance and the building of new mileage. In general, but not specifically, deterioration becomes worse moving west to east. Some sections of track allow speeds of only ten miles per hour, definitely hampering the efficiency of a unit train on a tight time schedule and reducing total utilization. Rail and tie replacements are presently at below average depreciation rates so that track conditions are deteriorating or, at best, staying the same. Eventually, either a new effort must be made to develop labor saving methods of track construction and maintenance or a totally new concept of track, tie and roadbed design must be initiated.

In the past, railroads appear to have set rates (prices) which did not have a unique relationship to the underlying cost estimates. In a 1963 report to the Secretary of Commerce (3), this was expressed as follows:

> "Pricing murt depend upon knowledge of cost and components of cost. Until sufficient cost data are available, rates quoted by the railroads cannot accomplish their purpose of effective competition at a profitable price. The railroads have never instituted cost-finding procedures as a reference for pricing services. Although several different sets of books have been kept traditionally to meet the separate requirements of the ICC, the IRS, the various state reporting criteria and for responsibility accounting, none of the bookkeeping operations offers a basis for costing service."

To some extent this has changed since 1963, but with respect to unit train operations, pricing of the service still retains a strong element of charging what the market will bear based on estimates of the cost of service of competing lines or transport modes, if any. Estimation of the economic cost of services not only provides a calculation of resource allocation, but it can provide an open examination of the rate basis.

Probably the major catalyst to the formation of unit trains and the corresponding reduction of railroad rates on these one-commodity trains was incipient competition from a coal slurry pipeline in the east north central region, and, on the East coast, the reduction of crude and residual oil prices in the late 1950's and early 1960's. Some large coal users had felt an urgent need to reduce transportation costs and had financed the construction of a coal slurry pipeline in Ohio [4]. This pipeline posed a severe threat to the railroads as their largest volume commodity was coal and the proposed slurry rates were far lower than their single car coal shipment rates. A 1962 Department of Interior publication, "Report to the Panel on Civilian Technology on Coal Slurry Pipelines" [5], predicted the impact of slurry pipelines:

> "Since coal traffic is so important to the earnings of the railroads, especially in the East, we believe that they can ill afford to watch even a single new pipeline built without making every effort to minimize their own costs and adjust their own services in such a way as to meet the competition effectively, before the traffic is lost."

After a very short period of thought and a re-evaluation of their techniques and profits, the railroads, in cooperation with the electric utilities and coal mines, initiated the unit train concept. Driven by the instinct for survival, the railroads undercut the delivered coal price of the slurry pipeline and put it out of business in a few years. The Ohio slurry line was shut down. It was later proposed that it be reopened for the purpose of moving garbage from Cleveland. Currently, the only successful coal slurry line in the United States is the 273 mile Black Mesa line in the Southwest. It is by far the longest coal slurry, or any slurry, line in the world. One reason for its selection over unit train transportation was that the alternative was the construction of a 150-mile section of new track over rough terrain to serve the mine-to-powerplant route [6].

The unit train concept is not without its disadvantages, even when the track is already there. The trains are noisy, occupy significant track mileage and create hazards on level crossings. Rerouting and building new track to avoid cities and towns may become a necessity if any significant increase in their use occurs. Double tracking will serve to alleviate the traffic problem. Bridging and underpasses should eliminate the hazards. It may also become necessary to fence a signficant number of miles. These solutions are feasible but costly.

1.3 Coal Slurry Pipelines

The growing energy problem has resulted in research and development into new methods of utilizing current energy resources more efficiently. Among the recent energy transportation systems under study is the coal slurry pipeline. In the past, this method has had little support or publicity from either public or governmental agencies. Now, it is being acclaimed as one of the major energy breakthroughs. The actual success of this method, however, has not been entirely validated.

The idea of the coal slurry process was patented in 1891 [9]. Initially, the coal is mined and then sent by truck or conveyor to the slurrification plant. There, the coal is screened to remove oversize chunks. Subsequently, it is sent to a bin where it is crushed to a fine powder of sufficiently small particle size so that it can be suspended in water. Next the powdered coal is blown into a mixer where it is combined with a quantity of fresh water until a desired consistency is obtained. The slurry is then stored in tanks or delivered directly to electric power plant by pipeline. On arrival, the coal slurry is pushed through a centrifuge which is rotated at high speeds. There, the coal particles are separated from most of the water leaving 25 percent total moisture. Further dewatering by thermal drying (using very high temperatures), more filtration, and direct evaporation in open air storage tanks [7] has been suggested, but is deemed unnecessary in power plant applications. (Twenty-five percent moisture means an average of 2 percent heat loss.)

The most important aspect of the entire coal slurry process is the pipeline. The first coal slurry pipeline was built in 1914 to bring coal to London, England [9]. Since then, the United States has built approximately 381 miles of pipeline, with a capacity of almost 6 million tons of coal per year [8]. This includes the 273 mile pipeline, built in 1972 by the Southern Pacific Transportation Co., which runs from the Black Mesa coal fields in Arizona to the Mohave power plant below the Davis Dam on the Colorado River. The 1036 mile pipeline planned by Energy Transportation Systems, Inc., (ETSI) to deliver 25 million tons of coal per year from the coal fields near Gillette, Wyoming, in part to Middle South Utilities' power plants in White Bluff, Arkansas and in part to whichever other utilities are willing to enter into long term contracts, is the furthest advanced among several long distance coal slurry pipeline proposals. It is this recently proposed slurry pipeline which has suddenly erupted into a major controversy. Involved are railroads, ETSI, environmentalists, Congressmen, state legislatures, economists and engineers.

Both the Black Mesa and the proposed Wyoming to Arkansas pipeline basically involve the same mechanism. Along the Black Mesa pipeline there are four electrically powered pumping stations located 65 miles apart. Coal slurry is pumped through a pipeline 18 inches in diameter at about 3.5 miles per hour. This speed is slow enough to prevent erosion of the pipes from coal particles but fast enough so that the coal will not settle out of suspension in the pipeline. It takes three days for a particle of coal to travel the entire 273 miles.

At maximum capacity, the pipeline contains 46,000 tons of coal [6]. A fresh water pump is situated at each station in case there is a breakdown and flushing of the line is necessary. There are also additional fresh water storage ponds and an emergency dump pond at each pump station.

The Wyoming to Arkansas line is based on a similar scheme. The pipe is 38 inches in diameter. The entire pipeline will be below ground except for the 10 pumping stations located 100 miles apart and for river crossings, ravines and difficult terrain. It is a 12 day 9 hour trip for a particle of coal. At maximum capacity the pipeline contains 855,000 tons of coal [7]. All other characteristics are generally similar to those of the Black Mesa line. The pipeline route was chosen to provide as much downhill grade as possible, a factor which eases the strain on the pumps and reduces cost. The route from the Black Mesa mine to Davis Dam has an overall decent of 1,592 feet. The Wyoming to Arkansas route has a similar, but milder decent [8].

Over particular routes, the coal slurry pipeline has several advantages over other forms of coal transportation. For example, the Black Mesa coal mines are located 120 miles north of the nearest railroad. Davis Dam is located 30 miles north of the nearest railroad. Had the coal been shipped by rail, the total distance would have amounted to 400 miles, including 150 miles of new rail facility [6], or 127 miles more than the pipeline. It is important to note that the distance advantage here is of the order of 2:3. Water needs for the Black Mesa pipeline appear adequate; the underground wells are regularly replenished. However, there has been no environmental impact statement. In addition, the coal slurry provides almost 15 percent of the cooling water required by the Mohave power plant [8]. Overall, the pipeline is located in an ideal environment.

Some coal officials have observed this pipeline and are convinced that coal slurry lines are more beneficial than railroads as a method of transporting coal. Carl E. Bagge, president of the National Coal Association says:

> "The railroads already have a hopper car shortage and we anticipate that coal production will be up by 17.5 million tons next year." [9]

The seemingly ideal conditions that exist for the Black Mesa pipeline are in many respects not reproducible on the Wyoming to Arkansas pipeline. One of the primary concerns in Wyoming and South Dakota is the coal slurry water requirement. The entire slurry pipeline would require 10,000 gallons of water per minute, excluding additional water for emergency purposes which might be tapped at the head and/or along the route. This would have to be tapped from the Madison formation, an underground reservoir which extends into Wyoming, Montana, and North and South Dakota or transported about 200 miles from the river. ETSI claims that the water would be replenished by seepage from snows and streams [11]. Nevertheless, their assurances do not convince everyone. U.S. Congressman Teno Roncalio has stated:

> "Wyoming can't afford to export its water."

U.S. Senator William C. Hector has expressed a similar view:

> "The idea of taking our precious water table, which we really know very little about, and sending it to Arkansas is a very bad concept." [10]

Roy H. Guess, an advisor to the Wyoming legislature has said that he is not opposed to the slurry concept, but he doesn't want Wyoming water used. Opposition is also coming from local municipalities which obtain their water only from the reservoir. Additional opposition comes from farmers, who claim that the water is needed for agricultural purposes and from a coalition of western governors who do not want their share of the water reservoir taken. Despite this political opposition, ETSI already has been provided with a go ahead. In 1974, the Wyoming House of Representatives granted it permits to test drill for water. Now, however, some of the Representatives are trying to get the permits revoked [11].

ETSI has claimed that they would install a return line to recycle the water used after dewatering the slurry. However, a return line would have to move the water on an uphill grade, causing the pumps to consume a large amount of power. In turn, this would increase costs by 30 percent and make the entire project much less attractive.

The advent of any new industrial concept invariably brings with it the cries of the environmentalists. The case of the coal slurry pipeline from Wyoming to Arkansas is no exception. At this point in time, however, the environmentalists are undecided as to whether the slurry pipeline is good or bad. ETSI claims it would be the "least environmentally damaging system to bring Wyoming coal to Arkansas" [11]. However, many oppose the pipeline (as they would a rail extension), contending that it would stimulate increasingly massive strip mining of Wyoming land. Still others prefer the idea of a "clean," invisible pipeline to noisy trains and the ubiquitous railroad tracks.

The greatest objection to the Wyoming-Arkansas slurry pipeline comes from the railroad companies. Their counter-arguments include the increased job opportunities they provide and the favorable comparative costs of railroad improvement. To build the line, ETSI is seeking the right of eminent domain in order to permit it to dig beneath 49 sets of railroad tracks owned by the Burlington Northern, the principal railroad company competing in the proposed ETSI area, and other companies. Congressional action is expected in the coming year. Ironically, the railroads have also used this right, at the state level, during their expansion. The orginal western development, however, was based on what were, in effect, land grants.

The railroads have much at stake in the pipeline dispute. The possible effect on transport prices is obvious. If the line is developed, railroad rates for coal transport must be dropped if they are to remain competitive. Even more important to the railroads, however, is that coal traffic constitutes their most important source of future expansion and present stability. Coal movement currently constitutes about 25 percent of total freight business. For specific railroads, the percentage is significantly higher. Given their fixed costs, the loss of coal traffic might require higher charges on their remaining business if they are to remain solvent. In many traffic categories this will prove impossible as shippers employ alternate modes including trucks and barges. The resultant increase in these modes will bring their own problems: highway and waterway congestion, air and water pollution, additional road building, the construction of more dams and locks, and the loss of transport flexibility as well as the defense related strength that the railroads represent. It may be cogently argued that much of this could be, and could have been, avoided if the railroads instead of raising prices to compensate for lost revenues lowered them to compete for lost business. Aside from the cash flow problem, which is teleologically local, the reality of the current situation is that railroads do not think this way unless forced to do so in the *extremis* of major competition. In this they are supported by the weight of past ICC decisions and the National Transportation Act.

Executives of the Burlington Northern have claimed that the slurry pipeline would cost their company nearly $225 million in lost revenue each year [11]. They claim that by granting ETSI the right of eminent domain, and thus the ability to build the line without seeking eminent domain on a state by state basis, Congress would accelerate the destruction of the already economically troubled railroad industry [13]. Second, that the proposed pipeline would supply a basically fixed amount of coal to only a few chosen contract customers on a take or pay basis whereas the railroads are common carriers, required by law to serve all customers [13]. While the pipelines would, under regulation, be required to serve new entrants, by prorating capacity if necessary, the railroads fear that the contract provisions will foreclose them from a significant segment of the market for the contract period. Third, it is claimed that the pipeline would threaten the needed improvements on existing lines. The improvements could be justified only by the anticipation of continued and increasing large coal shipments [13].

The railroads offer few alternatives although they have not, as yet, joined the eastern roads in rate increases. In response to the Bagge statement (cited above), they argue that there is no longer the hopper car shortage that existed in the past. Furthermore, they are sure that they will have the capacity to increase coal shipments from the current level of 16 million tons per year to the anticipated 140-150 million tons required within the necessary time period. But they suggest that this can only be done if the pipeline does not divert steel from the railroads [10] and if the cream of the coal shipments is not skimmed by exclusive contracts.

The steel requirement for the slurry line is not insignificant. Up to a million tons of steel would be required for a 1000 mile 25 million ton per year pipeline. The steel would not be recycled. A typical unit train requires 30,000 tons of steel. To ship a similar amount of coal 1000 miles by unit train would require about 500,000 tons of steel, most of which can be recycled.

There are still a number of uncertainties connected with pipeline efficiency. For example, the Black Mesa line must always opurate at its full 64,000 ton capacity. The operating speed cannot fall below 3 miles per hour. Its design speed is 3.5 mph. If the load falls below 65 percent of capacity, it is claimed that the entire pipeline operation becomes uneconomic (6). (Reducing capacity to this level can be accomplished by reducing line flow to 3 mph and increasing water use to 63 percent of volume. Unit costs increase by about 50 percent. If 75 percent capacity is assumed, unit cost increases are about 20 percent.) As this definition of economic rests on a rail price comparison rather than engineering efficiency it is possible that, with lower rail rates, the range of permissible throughput decrease is much less (say only 75 percent of capacity) before the line becomes uneconomic or pipeline tariffs must be raised.

The possibility of pipeline breakage and power outage is another matter of concern. In the event of pipeline breakage, all the slurry behind the break point would have to be dumped (the coal slurry itself is virtually unstoppable; it might be said that it has the consistency of a "black toothpaste"). Suction created by pumps downstream of the break point might not be able to pull the remaining slurry through, depending on where the break is located. A power failure at any one of the pump stations would result in the dumping of all the slurry immediately ahead of the disabled pump station. Actually, each station would have an emergency dumping pond. However, any slurry dumped into these ponds could not be easily reclaimed and subsequently reintroduced into the pipeline.

These ponds would be completely useless for pipeline breaks between pumping stations. Any attempt to stop the slurry could result in a massive plugging of the line [12].

Perhaps the greatest hurdle facing the slurry pipeline is its cost. It has been reported that the initial cost is $750 million (in 1974 dollars) or $1034 million in 1975 dollars. (This estimate may be low as the index for U.S. pipeline construction from 1972 through 1974 has risen by 58 points, 221 to 279 with 1947 = 100. The high of the construction cost trend range for 36 inch pipe including right of way, labor, materials, etc., has increased an average of 94 percent between 1974 and 1975.) Operation and maintenance charges would amount to $180.6 million annually (also in 1975 dollars). This may be compared to the $298 million (1975 dollars) required to upgrade existing railroads to handle the same tonnage of coal shipments [12]. Depreciation charges against a unit train are estimated at 8.6 percent of operating cost while those of the pipeline are 27.4 percent [12]. This points up a significant financial problem. To operate, a pipeline must be in place. The major costs are front ended. Any subsequent operating problems or decrease in coal supply or demand affects the highly capital intensive pipeline far more than it does the railroads. For insurance, this would have to be factured into the anticipated pipeline tariff.

It has been estimated that to pulverize, slurry, and ship the coal by pipeline would cost 1.1 cents/ton-mile compared to 0.8 cents/ton-mile by rail [14]. Additionally, the railroads haul a wide variety of freight and have substatial flexibility in throughput. With respect to coal alone, crushing, grinding and beneficiation could be done at the consuming end, avoiding water problems, and, as the operation can be tailored, serving a wide range of customers. It is more likely that preliminary crushing to 2x0" or larger size followed by washing would be accomplished before loading. Upon delivery by unit trains, this would be pulverized to 230 mesh size. By comparison, the pulverized coal shipped by slurry pipelines, [19] would be crushed to a 20 mesh size and washed before loading. However, as washing must be done at larger coal size, this requires a two stage crushing process. After drying at the receiving end the moisture content leaves it in the form of a damp clay which must be pulverized to achieve particle size for boilers. It is not suitable at this size for present coal gasification plants.

The logical question is why the promoters are interested in its construction. One answer, of course, is that they sincerely believe that the pipeline will prove to be the low cost operation. Another answer is provided by eastern U.S. railroad history in the first third of the 1800's. It will be recalled that railroads then were built by construction companies backed by promoters who sold railroad bonds and stocks (often with the full faith and credit of the states involved) to individuals and investment houses here and abroad as well as to the cities and towns through which the railroad was to pass. The construction companies were paid as the work progressed, the promoters earned commissions on the securities sold. By and large these early roads went bankrupt as did those who operated on them. Nine states defaulted on their full faith and credit obligations after a vain appeal to the federal government which invoked a form of state's rights. An engineering-construction company is not an obvious candidate to sink a very large sum of money into a project with a payout period of 30 years and a rate of return governed by a regulatory agency. They can do better than that. A well known investment house is an even more unlikely candidate. A probable scenario if the line is built is the almost immediate divestiture of the Bechtel-Lehman Brothers interest in ETSI by the issuance of public shares. Both then will have capitalized their investment. And, history may repeat itself.

The pipeline is relatively capital intensive, the railroads are relatively labor intensive. The latter may change with different work rules and with unit train operation, the former cannot. The result is that the former may be a victim of its fixed charges, throughput, and debt structure and the latter to inflation. Aside from this, however, it should be noted that in a less than full employment economy, and one in which conservation is becoming more important, an industry which is relatively labor intensive, which recycles a portion of its fixed real capital input, and which is flexible as to time of purchase and disposition of its equipment, may not be all bad. When operating, the pipeline would employ 245 people in the direct labor category; the railroad 1500. Railroad construction and maintenance can use people who already live in the area and will continue to do so. Pipeline construction is largely a specialists job. It carries its own breed of migrant workers, creating boom town conditions and problems along the route of the line with only the boom town clean up after the line has been buried. It is simply not clear where the labor advantage lies; much depends upon the stance of the observer.

1.4 Extra High Voltage (EHV) Electric Transmission

An alternative method of coal transportation involves the production of mine mouth electric power with subsequent transmission of large blocks of power on a point to point basis. Two methods are available: AC and DC transmission. The former appears to be best suited for distances of less than 500-600 miles and for systems in which the trunk line is tapped at intermediate points. For longer distances and single origin-destination pairs, DC transmission appears to be more economic.

This study is limited to 3000 Mw transmission lines. Both AC and DC lines are compared. A general analysis is presented for both followed by a route specific analysis of five origin-destination pairs. The output in this part of the study is considered more tentative than that for slurry pipelines and unit trains because the cost data are more unreliable.

1.5 Right of Way Costs

Where a right of way has not already been established (slurry pipelines, transmission lines, and new rail routes or diversions), right of way costs are only speculative. Rail routes involve the total alienation of land from other uses although the corridor so provided might be used by other transport modes. Pipelines and electric transmission do not alienate land completely but rather require easements on property. In electric transmission, about 90 percent of all rights of way are easement purchases. The remainder include land in fee, eminent domain condemnation, and leased land obtained from other utilities or the government. The easement involves a one time payment for a perpetual agreement and may include any of a large number of special stipulations. The payment tends to run about 100-150 percent of the current land value. Provision is usually made for damage payments if the easement must be utilized to repair facilities. For electric transmission, danger tree rights are also obtained. Payments are usually at cord wood or pulp wood prices.

Widths of right of way vary considerably. However, the basic need for both a slurry line and a transmission line include safe width and provision for a construction road. Where a line can be built along an existing roadway, costs are suitably reduced.

In this study, nominal right of way costs are used, however, an indication of the variation is given in Table 1.2. While the table is specific for crude oil and product pipelines it should be sufficiently indicative for both slurry lines and EHV transmission. With respect to the latter, however, it may be noted that a 765 kvAC line corridor may be from 225-250 feet wide while a ±600 kvDC corridor may be only 175-200 feet. Problems of electrical discharge may suggest a right of way of 300 feet for both.

Table 1.2

ONSHORE PIPELINE RIGHT OF WAY AND DAMAGE COSTS
(dollars/mile)

Region	High	Low	Average	Range
North East (Pa, Mass, NJ)	58275	8028	25660	8028-58275
South East & Central (La, Ark, Miss, Tenn)	11667	6476	6542	1621-16211
Mid-Atlantic (WVa, Ky)	5702	5006	5465	2039- 7974
E. North Central (Ohio, Ill, Ind)	23889	3828	14753	250-33500
Central (Okla, Neb, Kan)	4884	1399	3123	1188- 9207
South Central (Tex, NMex)	1910	1727	1818	793- 3027
North Tier (East) (Wisc)	11137	11137	11137	11137
Mountain (Mont, NDak, Colo, Wyo)	1995	1489	1742	634- 4017
West Coast (Wash, Ore)	21735	14121	17928	14121-21735

New Individual Projects ($/mi)

W.Va. = 6168
La. = 25700
Okla. = 800
Iowa = 4087
Mich. = Ill. = Ind. = 50,633
B.C. = Calif. = 8340

Source: Oil and Gas Journal, August 18, 1975.

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SECTION II

UNIT TRAINS

2.1 General.

The route specific analysis of unit trains is principally a function of the terrain. For example, traffic bottlenecks along routes to the west can be caused by winding roads which reduce speed along the sections involved. As a result, for a given rate of coal shipment, expressed in millions of tons per year (MMTY), an increased number of trains must be used. Alternatively, operational flexibility can be purchased at a higher than route design cost. If utilization decreases, rolling stock may be leased (at a reduced rate); if it increases, additional stock may be rented (at a premium). Increased shipments over time can be accomplished with the same number of trains by upgrading the road condition to accomodate higher train speeds. The upgrading can be undertaken over an optimal time horizon determined by a dynamic (rather than a static) analysis.

2.2 Capital Costs.

Traffic congestion along a double tracked railroad is not a problem if the annual capacity is less than 70 MMTY. Train spacing of one hour can be maintained assuming 105 car trains carrying 10500 tons per train. The assumption of only 25 MMTY allows more than 2.5 hour spacing which permits shipments of other commodities. We have assumed that even this spacing calls for the building of by-passes around population centers and the building of additional bridges and highway crossings. On the western routes strengthening trestles and

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straightening some of the curves is needed to reduce the bottlenecks. However, there are fewer towns to get around and highways to cross than on the eastern routes. We have used an average of 15 percent for new railroad to be built for each route. This requires a new 300 ft. right of way at an estimated average cost of $1000/mile. Land values may, however, range from $300/acre in scrub areas with relatively low population density to $2500/acre for central Illinois farmland. Rerouting would avoid populated suburbs for the same noise and traffic reasons that preclude the use of unit trains through cities and towns.

Except for the facilities, distribution is not considered an important cost factor in unit train operation. The trains unload directly at the point of consumption. However, we have assumed that at the gathering and the mines may require an equivalent of 100 miles of upgraded railroad plus fifty 125 ton trucks.

The proposed upgrading of the right of way includes replacement, over a three year period, with 155 lb/yd tracks (132 lb/yd track is currently used by the Burlington Northern) and 6200 ties/mile. Subsequent replacement is indicated in the replacement schedule. The steel is assumed to be carbon steel of 0.69-0.82 percent carbon and below 0.04 percent phosphorous (to prevent "cold" shortness) and below 0.5 percent sulfur (to prevent "hot" shortness). This upgrading, although charged to coal shipment alone in the present analysis, will aid general shipments and by increasing unit train costs tends to render our estimates and coal slurry comparisons conservative. Replacement of all ties along a 1000 mile double tracked route implies 47 million feet (total length) of No.5 wooden ties (9"x7"x8.5'). These are placed on 21.5" centers. This amounts to over one million trees per year over the three year period. While wood ties are generally available, because of environmental or other factors, they may be replaced in the long run by concrete ties which would be mass produced. About 800,000 tons of concrete would be needed per 1000 miles of double track. The resiliency of concrete ties can be improved by using flyash in the mix as in the building of airport runways. Detailed costing, given in the previous analysis by Ferguson [1], has been escalated for the present analysis. Here it may simply be noted that the issue of concrete vs. wood ties is not closed. Concrete ties are used on European and at least one southern U.S. road, although for relatively light loads. The Canadian National proposed to use them in the double tracking of some of their sections. Even their failure in the Black Mesa operation is inconclusive. There the cars used were 125 ton rather than 100 ton. Questions have been raised concerning their contact with the roadbed and their initial condition. Finally, not all of the concrete ties have been replaced. Wood ties have been substituted on the curves.

The unit train routes specified in Sec. 1.1 are detailed in Table 2.1 which shows for each route the miles of new road needed, miles of road upgraded, plus an equivalent of 100 miles of upgraded gathering road. Bottlenecks occur when sections of track do not permit the scheduled speeds on upgraded track. It can be seen in Table 2.1 that the incentive to maintain fast trains over a given route decreases as the bottlenecks increase. This is of particular concern on the westward routes. We have expressed the bottlenecks for the 30-60 mph (30 mph loaded and 60 mph empty return) and the 50-60 mph operation in terms of percentages of the total distance which must be travelled at 10 mph and the corresponding number of trains needed for the shipment of 25 MMTY of coal. More trains increase capital costs while slower speeds increase labor costs.

Locomotives are assumed to be 3000 hp diesel electric costing $330,000 each. The hopper cars are 100 ton cars costing $27,000 each. Both are in 1975 dollars. The estimates are

Table 2.1

UNIT TRAIN ROUTES

Route*	New Road Miles	Upgraded Miles	Percent Bottlenecks	Number of Trains 30-60	50-60
(1) Farmington, NM to Los Angeles, CA. Coal: 11630 Btu/lb(dry) 8600 Btu/lb(as mined, 16.3% moisture)	100	750	0	18	14
			10	24	21
			20	30	28
(2) Gillette, WY to Chicago, IL. Coal: 10080 Btu/lb(dry) 7770-12780 Btu/lb (as mined, 30.8% moisture)	165	935	0	22	17
			10	29	25
			20	36	34
(2a) Gillette, WY to Chicago and on to New York.	100	1720	0	39	29
			10	52	44
			20	65	58
(3) Gillette, WY to Houston, TX. Coal: 10080 Btu/lb (dry) 7770-12780 Btu/lb (as mined, 30.8% moisture)	210	1190	0	28	21
			10	36	31
			20	44	42
(4) Colstrip, MT to Houston, TX Coal: 10550 Btu/lb (dry) 8600 Btu/lb (as mined, 22.3% moisture)	240	1360	0	31	23
			10	41	35
			20	50	47
(5) Colstrip, MT to Seattle, WA. Coal: 10550 Btu/lb (dry) 8600 Btu/lb (as mined, 22.3% moisture)	158	892	0	21	16
			10	28	24
			20	34	32

*For each route 100 miles of upgraded gathering road has been added to give the total distance.

consistent with those provided by the Association of American Railroads, the Burlington-Northern and the Chessie system. The number of trains are estimated on the basis of 274 days of operation per year with a 5 percent reserve. As an alternative, the railroads suggest a 10 percent car and 15 percent locomotive reserve. The number of trains for each operation may be compared with the national total (July 1, 1975) of 306 unit trains of which 191 or 62 percent carried coal.

Annual fixed charges are based on funding with 60 percent debt and 40 percent equity, assuming 9 percent interest on debt and 15 percent on equity. During construction, compensation by interest on uncommitted capital is available. Depreciation for roadbed, right of way and structures is taken over 30 years, the life of the project. However, average life of cars may be taken at 15 years with minimal maintenance and 20 years with adequate scheduled maintenance. This implies the scheduled purchase of new cars. Locomotives may be expected to last the entire 30 year period, excluding obsolescence. Depreciation is therefore taken over 20 years on cars and locomotives and 30 years on other facilities. It is assumed that additional rolling stock is purchased as necessary. The gross difference in the treatment amounts to less than 2 percent of total costs.

If, for any reason, operations should fall below full capacity, it would be possiblu to lease both cars and locomotives. Alternatively, at over capacity, both may be leased for route use. The former may result in as little as 50 percent capital recovery, while the latter may result in a doubling of rolling stock costs. Coupled with the debt burden on right of way, which would be spread over a smaller revenue, unit costs would be increased. We feel that our assumptions are too wide and thus, for comparative purposes, conservative.

A sample route and capacity specification for Farmington to Los Angeles is shown in Tables 2.2-2.4. Here the assumptions are full capacity, 30-60 mph speeds [2] and no bottlenecks.

2.3 Operating Costs.

The operating costs may be summarized in terms of fuel, labor and supplies.

The fuel is equivalent to No.2 fuel oil, although it may be somewhat heavier. For comparison purposes, No.2 fuel oil contains 5.90 MMBtu/bbl, distillate fuel oil contains 5.96 MMBtu/bbl, and railroad diesel contains 6.06 MMBtu/bbl. The heavier the grade, the more Btu's, the fewer the barrels needed, and the lower is the degree of refinery severity needed. It should be noted that the railroad-automotive diesel range extends from about 5.6 MMBtu/bbl (44° API = .806 sp.gr. = 7.08 bbls/ton) to almost 6.4 MMBtu/bbl (14° API = .972 sp.gr. = 5.87 bbls/ton). We have assumed a price of 30 cents/gallon. Mid-continent spot prices for No.3 distillate are currently 28.50-31.85 cents/gallon and for No.5 oil (Chicago, one percent sulfur guarantee) are 29.76 cents/gallon. Spot prices are higher than contract prices and heavier grades are cheaper than lighter grades, hence, our estimate is high (conservative). Fuel costs should be escalated at about 7 percent per annum.

Table 2.3 shows a sample detail of labor requirements for the case presented in Table 2.2. The basic procedure in Ferguson was used for this and for the 1975 costing. It compares closely with SRI and Burlington Northern trends. Table 2.4 shows a sample detail of the supplies estimate for the same case.

The average current (1975) cost, including capital, can be accounted for by an assumed rate of 7 percent escalation

Table 2.2

SAMPLE ROUTE AND CAPACITY SPECIFICATION

Route: Farmington, NM to Los Angeles, CA
(850 miles plus 100 miles gathering)

Facility Name: Coal Unit Train and Rail Line

Prime Input: 25 million tons medium rank bituminous/year

Other Input: Electricity, diesel oil

Prime Output: 25 million tons medium rank bituminous/year

Other Output: Shipment - 30 mph loaded, 60 mph empty (30-60)

Days/Year of Normal Operation: 274

Description and Size:

- 10,500 ton unit trains. (18 trains)
- Each train made up of 105 hopper cars each with a capacity of 100 tons.
- Coal storage area, feeders, conveyors, and loadout bin and chute with loading capacity of 3,200 tons/hour.
- Round trip distance: 850 miles (100 mile gathering)
- Normal round trip cycle time: 48.5 hours.
- 5 3,000 hp diesel locomotives per train.

Table 2.3

SAMPLE DETAIL OF LABOR REQUIREMENTS

Detail Labor

A. No[illegible]anual	
1. Technical Supervisors & Managers (Executives, foremen)	60
2. Nontechnical (Drivers, Dispatchers)	15
A. Total	75

B. Manual		
1. Operating Labor		
Engineers	109	
Firemen, Breakmen, Flagmen, Signalmen	540	
		649
2. Maintenance Labor		
Electrician	60	
Carpenters & masons	256	
Blacksmith	24	
Machinist	36	
Laborer, cleaner	155	
Other	350	
		883
B. Total		1532

Table 2.4

SAMPLE DETAIL OF SUPPLIES

(Case in Table 2.2)

Detail - Supplies	Million Dollars		
Locomotive repair (98)			2.15
Car repair (1880)			1.80
Road and Shops and Machinery:			
1. Road and Buildings:			
Ties	0.62		
Bridges, trestles	0.36		
Building, Shops	0.20		
Fence and Signals	0.05		
		1.23	
2. Stationary	0.02		
3. Chemicals and Track	0.41		
4. Stone, glass, ballast	0.20		
5. Metal Products:			
Rail	0.20		
Tools	0.01		
		0.84	
6. Miscellaneous Supplies	0.20		
7. Shop Machinery	0.15		
8. Electrical Equipment	0.26		
9. Roadway Machines	0.16		
10. Signal and Interlock	0.30		
11. Miscellaneous Repairs	0.04		
12. Power, Light, Water	0.05		
		1.16	
Total R&S&M			3.23
Total Supplies			7.18

from the date of the original estimates. The confidence level of the overall unit cost estimate is ±5 percent to ±10 percent.

2.4 Cost Analyses and Results.

Table 2.5 and notes show the basic items of costs and resources for a specific route and for a given set of operating parameters. Also included in the notes are the cost base at over and under capacity.

The results of computations for specific routes are given in the computer printouts included in the Appendix to this section. A typical plot of curves is shown in Figure 2.1 for various routes in dollars/ton at various capacities and speeds of 30-60 and 50-60 mph. The analysis shows that:

(1) Ten to twenty percent over capacity may give a lower shipping cost than at full capacity by increasing operating days to 328 per year from 274 days per year. This means, however, operation without reserve and cannot be sustained over a long duration. Traffic problems involving other commodities may also be expected.

(2) With more than 10 percent of 10 mph bottlenecks along the road, there is no incentive to operate the road at 50 mph loaded rather than 30 mph loaded for a shipment of 25 MMTY.

(3) As long as the road condition is upgraded to sustain a 50-60 mph operation, an increase in capacity can be achieved by leasing additional

Table 2.5

Basic Items
Costs and Resources
(costs in million dollars)

25 MMTY - ________ miles one way, HV________Btu/lb

Route: __________; ___-60; ___% bottlenecks; +___% Capacity

Actual tonnage: 25 MMTY(1 +___% Capacity)

CAPITAL COSTS:				
Road				
Gathering at mines, trucks & hoppers		15.5		(1)
New right of way		____		(2)
New road		____		(3)
Upgraded		____		(4)
Equipment				
Locomotives & cars		____		(5)
Loading & maintenance facilities		____		(6)
Total capital costs, sum (1) through (6)			____	(7)
ANNUAL FIXED CHARGE ON DEBT:				
Average rate base	____			(8)
Debt retirement		____		(9)
Federal Tax		____		(10)
Depreciation		____		(11)
Total annual fixed charge on debt, sum of (9)(10)(11)			____	(12)
OPERATING COSTS:				
Fuel costs		____		(13)
Labor costs		____		(14)
Supplies costs		____		(15)
Total operating cost, sum of (13)(14)(15)			____	(16)
Total annual cost, sum of (12) and (16)			____	(17)
UNIT COSTS:				
Dollars/ton = (17)/Actual MMTY				(18)
Cents/ton-mile = 100 × (18)/(miles one way)				(19)
Cents/MMBtu = (18) $10^5/2$(HV)				(20)
Cents/MMBtu-mile = (20)/(miles one way)				(21)

Table 2.5 Continued

ENERGY REQUIREMENTS:		
Locomotives	hp	(22)
Million bbl of fuel		(23)
Steel required: cars		(24)
locomotives		(25)
rails		(26)
Options: wood, ties, feet		(27)
concrete, ties, tons		(28)
EMPLOYMENT:		
Railroad		(29)
Capital per worker		(30)
Related industries		(31)

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Notes:

(1) Based on 125 ton trucks at $300,000 each.

(2) 300' wide right of way to bypass cities or to straighten out curves.

(3) Include bypass of towns, crossing, bridges in eastward shipments; less of these in westward routes but straightening of winding ways and trestles will balance out costs.

(3),(4) include 6200 ties per mile, wood or concrete.

(9) 30 year amortization, 60% debt and 40% equity; 9% interest on debt and 15% on equity. Inflation rate may be used for cost escalation. During construction, compensation by interest on uncommitted capital is expected.

(13) 36¢ per gallon escalation at 7% per annum.

(14) 40% operating, 55% maintenance, for 30-60 miles per hour.
37% operating, 58% maintenance, for 50-60 mph operation.
5% administration.

(15) 45% on road, 30% on locomotives, 25% on cars for 30-60.
48% on road, 33% on locomotives, 20% on cars for 50-60.

Operating at reduced capacity of -20, -40, -60% include leasing out of equipment, recover conservatively ½ of the capital cost and full cost of maintenance and lay-off of 15, 30, and 45% of labor force.

Operating at over capacity:

+20% work 328 days with same equipment, increase maintenance plus overtime. This generally will lead to more economical operation momentarily but without reserve.

+40% include renting of equipment at double of own cost plus overtime on labor.

locomotives alone. By increasing the number of locomotives by 140 percent in the case of 10 percent bottlenecks at 10 mph, the freight hauled can be increased to 117 percent with the same number of days of operation, and to 140 percent by working 328 days/yr. No additional cars are needed. Thus, the increase in capacity can be achieved by obtaining the best cost balance between cars and locomotives or for locomotives alone.

(4) The flexibility of rails is seen in that the costs in dollars/ton vary over 15 percent between the present 80 percent and 140 percent capacity levels.

(5) Increasing capacity from 5 to 25 MMTY over a 1000-mile two-way route is readily achieved in 3 years by scheduling such as:

	No. of Trains	Road Condition (Average)	MMTY
First year	8	65 percent 10 mph, the rest 40 mph	9
Second year	12	25 percent 10 mph, the rest 40 mph	12
Third year	20	100 percent average 40 mph	25

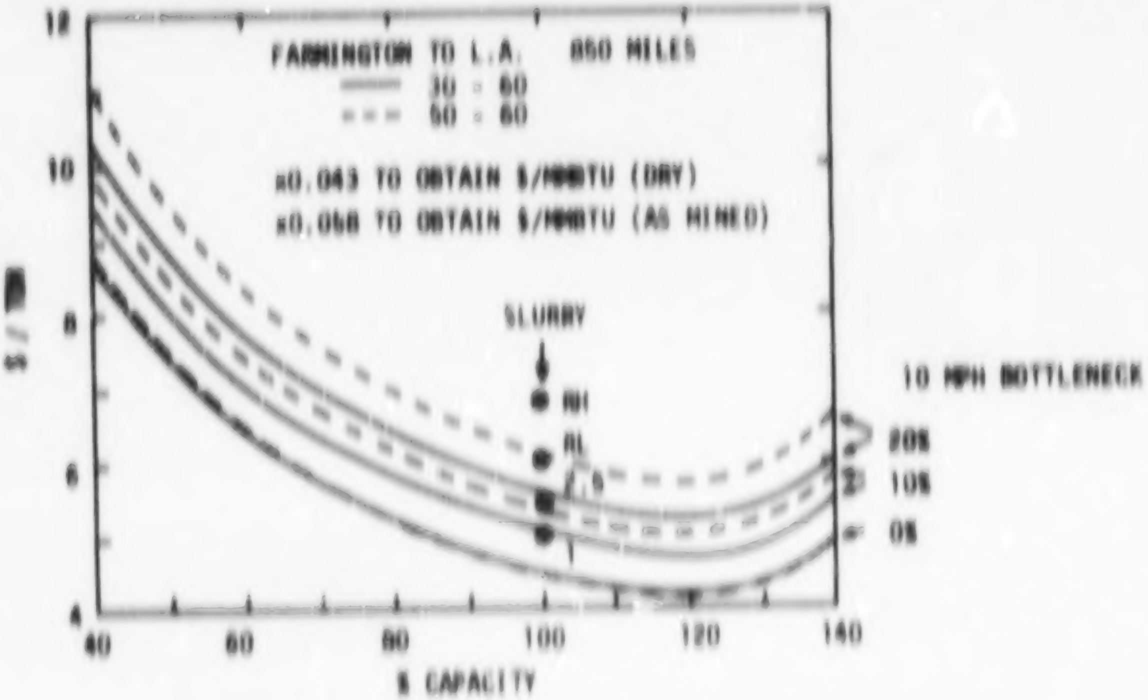
There is an optimum time schedule for upgrading the road and simultaneously upgrading the fleet of trains for a specific system. Such an optimum can be determined in a future study. Such scheduling prevents costs from increasing unevenly.

The choice of 30-60 or 50-60 miles per hour is a matter of balance of locomotive cost to car cost as well as labor cost. For a 105 car unit train, the break even is at a ratio of 1.53 in the number of trains at 30-60 mph to that of 50-60 mph based on the costs of locomotives and cars only. This ratio is rarely achieved, but the net saving in labor decreases this ratio to 1.17. Figures 2.1(a) to (c) further shows the effect of low speed bottlenecks, of say 10 mph. For shipment to the west coast, it can be seen that 50-60 mph does not have a great deal of cost advantage over a 30-60 mph rate.

Prominent in the cost of 50-60 mph operation is the cost of locomotives. This suggests that there is nothing sacred about 3000 hp or 3500 hp as a standard capacity for locomotives. For unit trains, the preferred single locomotive capacity would be at the 10,000 hp level and the number required would be about two for 30-60 and four for 50-60 mph operation. This is a desirable development toward the utilization of higher speeds (50-60) achieving greater saving at such speeds.

Some trend can be seen in the unit costs, in cents/ton-mile on various routes. Figure 2.2 shows that, because of the inclusion of 15 percent new railroad line, this cost increases with distance and the bottleneck percentage along the road. The increase is prominent for distances over 1100 miles. This differs from the cost of the single upgrading mode discussed in earlier studies [1-3], which showed that the cost in cents/ton-mile is nearly constant for distances over 500 miles. Both Figure 2.1(b) and Figure 2.2 show that shipment over a distance and route such as that from Wyoming to New York is hardly practical.

In Figures 2.1 and 2.2, multipliers are included to give unit costs in dollars/MMBtu (million Btu) and cents/MMBtu-mile on a 'dry' (D) as well as an 'as mined' (M) basis. Coal,



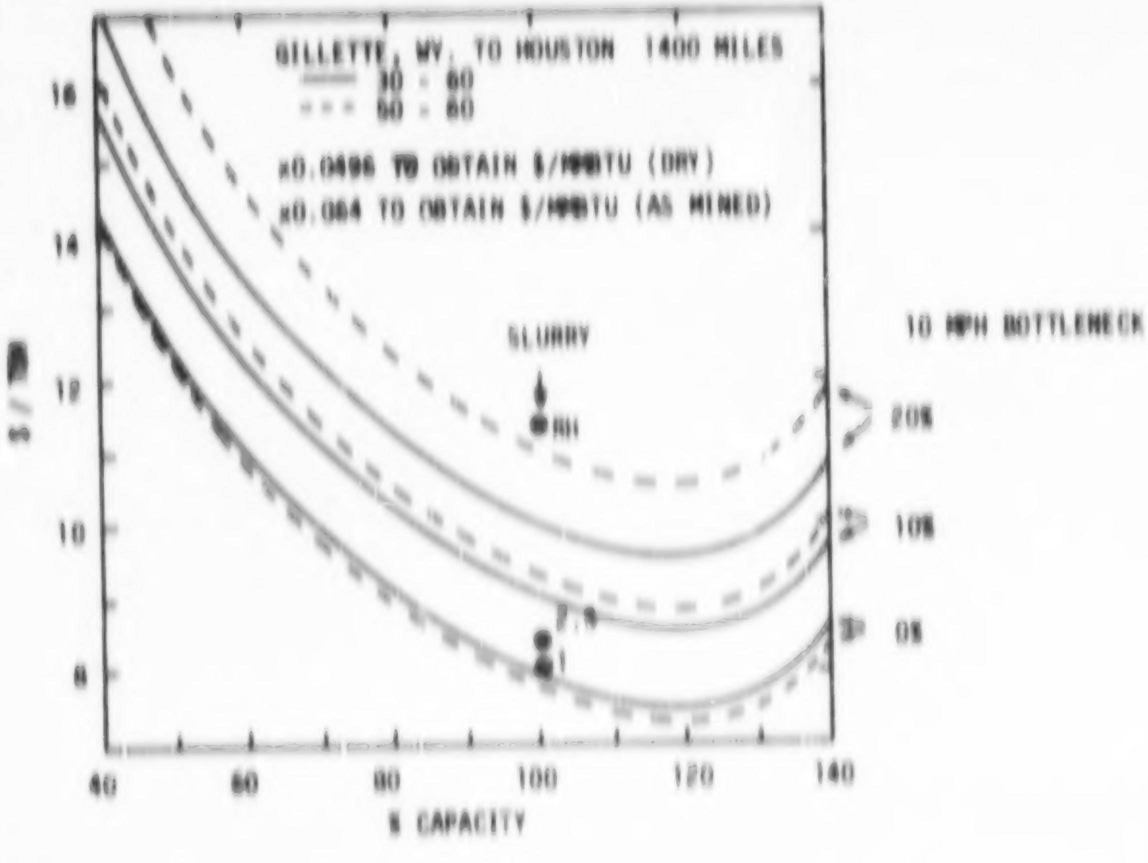


FIGURE 2.1(a) UNIT COSTS AT VARIOUS CAPACITIES - UNIT TRAIN

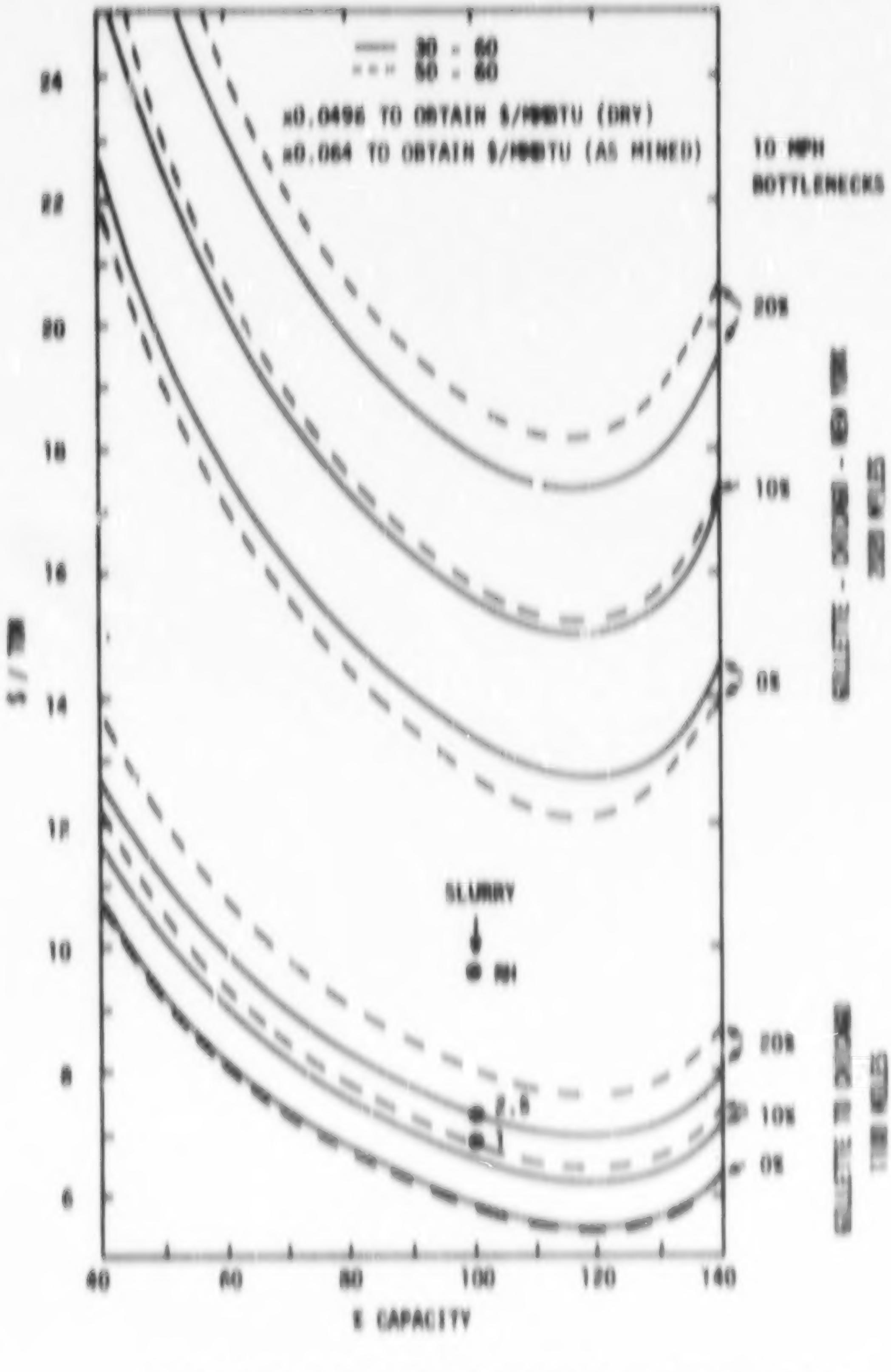


FIGURE 2.1(b) UNIT COST AT VARIOUS CAPACITIES - UNIT TRAINS

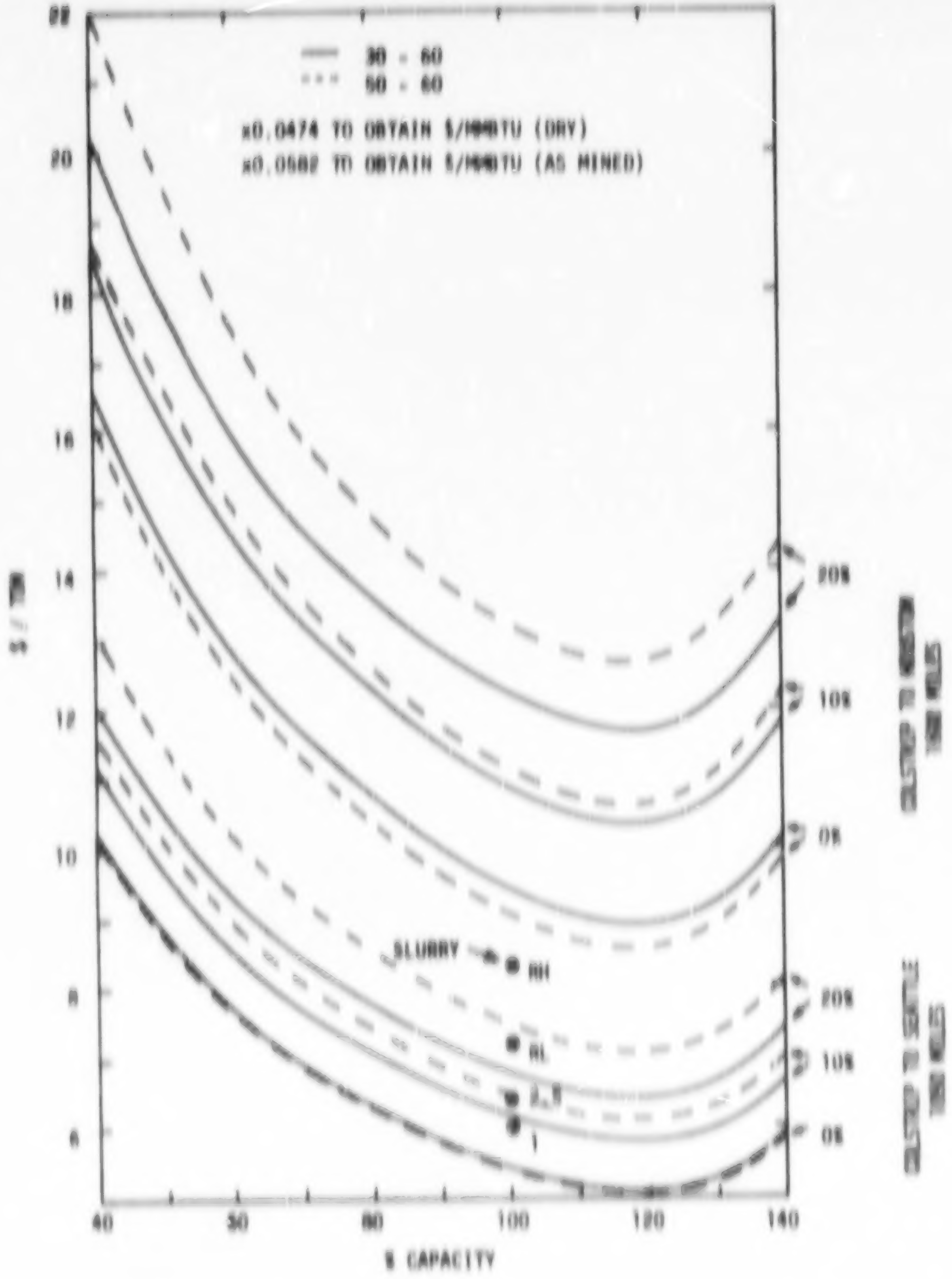


FIGURE 2.1(c) UNIT COSTS AT VARIOUS CAPACITIES - UNIT TRAINS

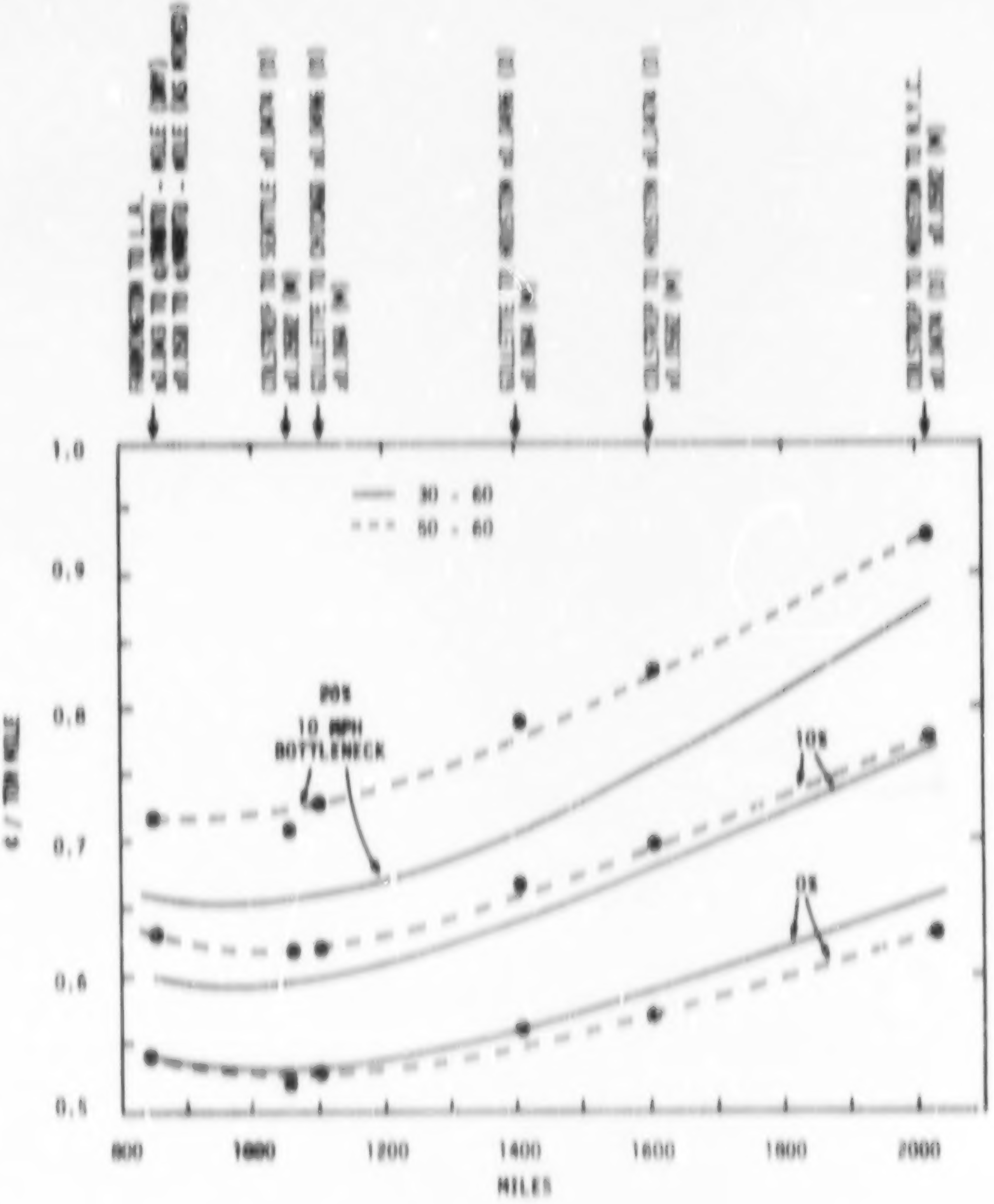


FIGURE 2.2 UNIT COST - UNIT TRAINS

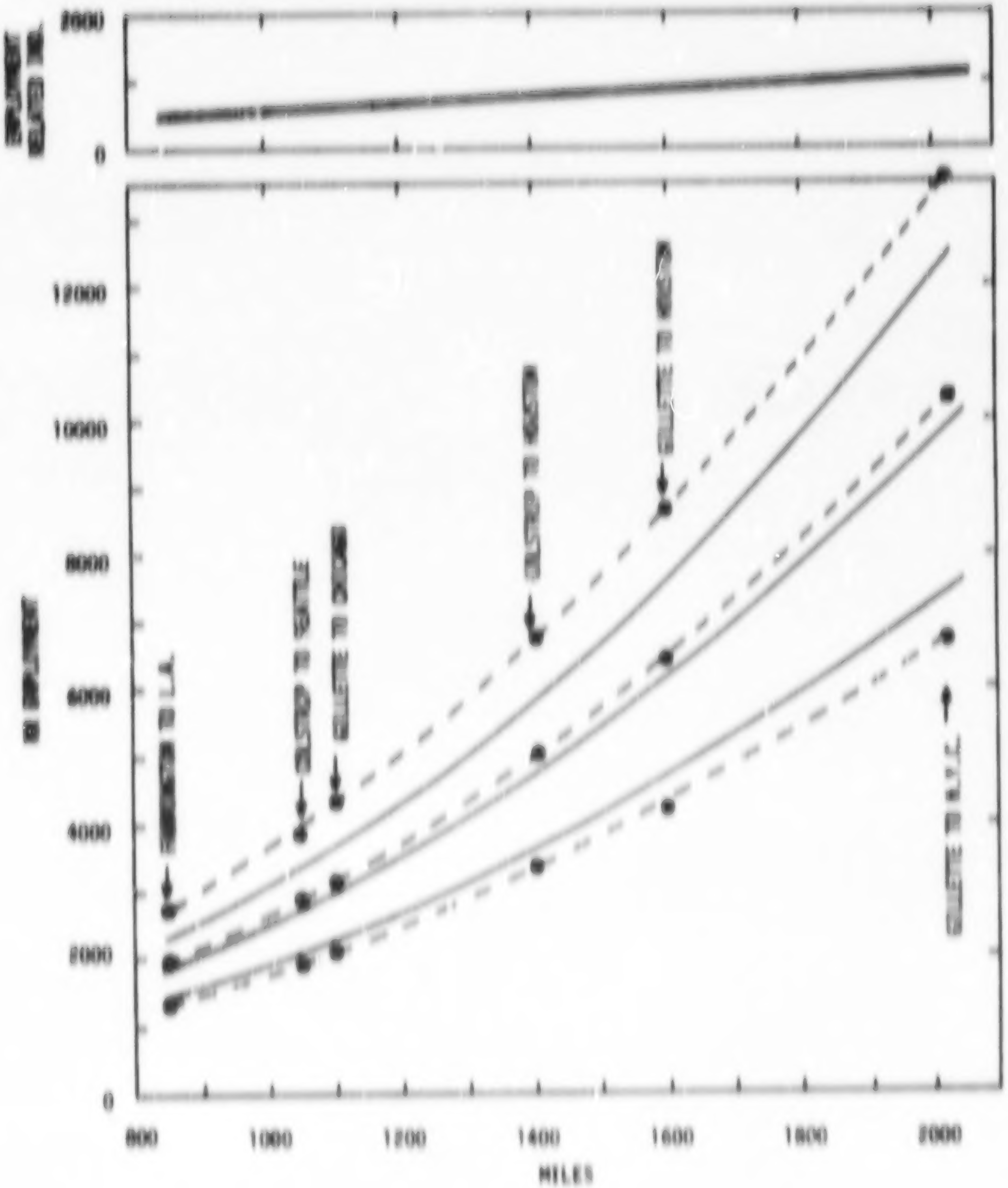


FIGURE 2.3 EMPLOYMENT - UNIT TRAIN OPERATION

as mined, may contain up to 30 percent moisture, depending on the particular mine. During above ground storage and shipment, moisture may be lost by evaporation. It may also be gained by exposure. Therefore both bases are given for comparison. Much depends upon the moisture content of the coal prior to loading onto the unit train.

Items included in the utilization of resources are employment, fuels, and materials. Figure 3.3 shows the level of employment for various modes of operation of unit trains for shipping 25 MMTY over various routes and the employment in related industries needed to sustain such an operation. Note that if all routes under consideration are activated, the increase in employment due to the unit train operation alone would be over 30.000, not counting those required for upgrading which would be at the 15,000 level, over a 3-year period. Other data from the Appendix, on various resource commitments, are shown in Figure 2.4. Of particular interest is timber consumption if wooden ties are used in replacement. This amount to the cutting of one million firs per year, over three years, for each 1000 miles of double track road. If concrete ties are used, there is a significant indirect fuel requirement. Together with other uses, a round figure would be one million tons of concrete per thousand miles of road, or three hundred thousand tons of cement. The steel committed for complete upgrading, especially the bulk of the rails, is subject to recycling in the course of replacement. Full consideration of resource needs confirms the previously mentioned desirability of an overall time dependent supply analysis designed to avoid shortages and uneven demand schedules.

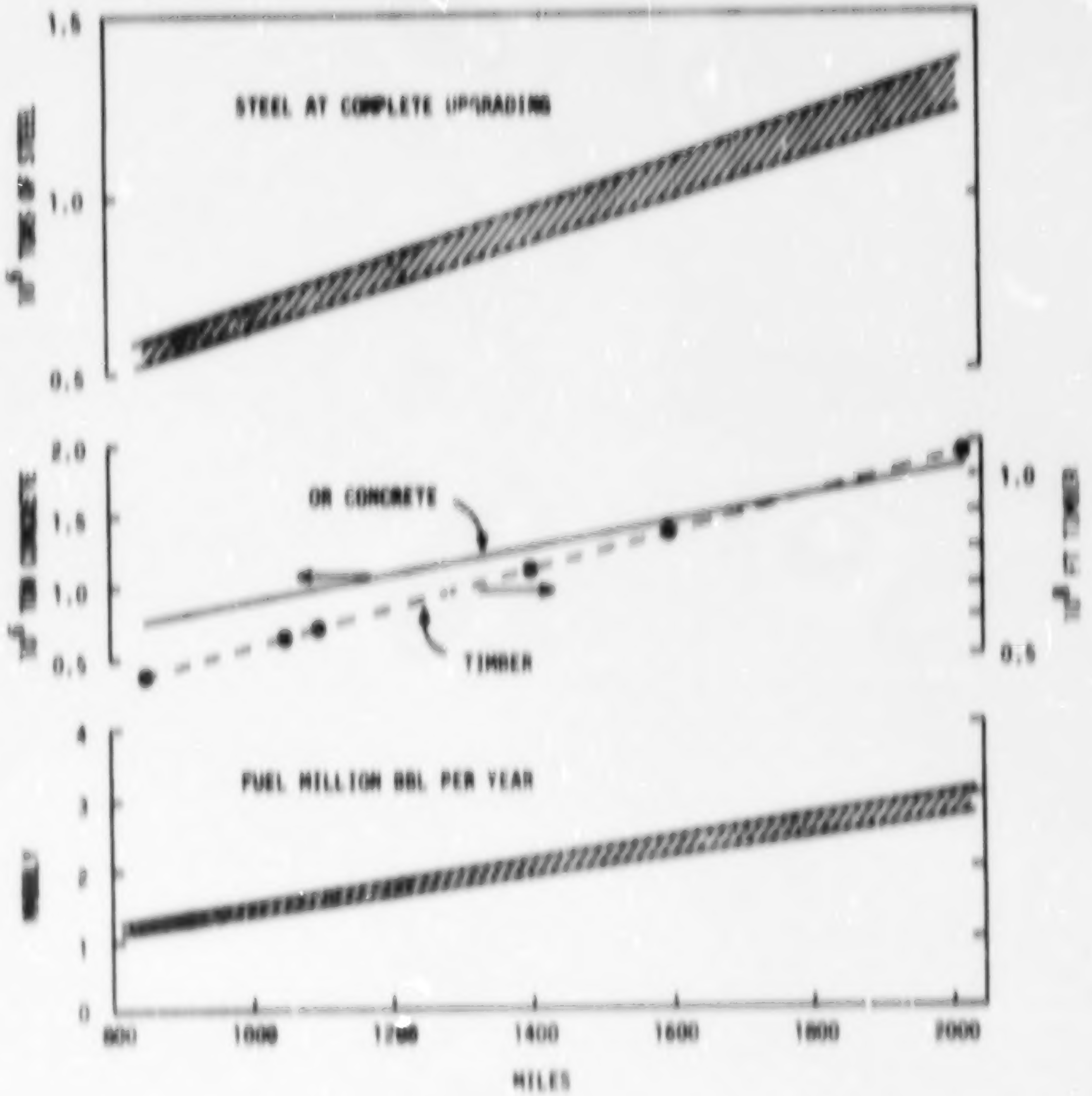


FIGURE 2.4 RESOURCE COMMITMENT

2.5 Additional Considerations.

2.5.1 Unit Train Characteristics. According to the Association of American Railroads, based on a sample of 191 unit coal trains operating on July 1, 1975, about 60 percent of these trains operate under contracts of 10 years or longer. A minimum annual tonnage requirement is specified for 80 percent of the trains. As a whole, these trains carry about 168 MTY of coal or about 73 billion ton miles. The average load is 877,000 T/Y/train; the highest being about 5.6 MTY. Average yearly train mileage is estimated to be 90,000 miles/year with 235,000 the maximum. Individual car mileages are somewhat lower due to out of service maintenance and repair time. The average round trip distance may be estimated at 1226 miles with a maximum of 2944 miles. An average of 86 cars makes up a train with a maximum of 131. Most of the cars are designed for 100 ton capacity. The average train payload is estimated to be 8502 tons with a maximum of 13,100 tons. Excluding an unknown number of spare cars to provide maintenance time, the 191 trains required 16,392 cars. Of these, 68 percent were open top hopper cars and 32 percent were high side gondolas. Hopper cars were 68 percent railroad and 32 percent owned or leased by others. The gondola cars were 39 percent railroad and 61 percent owned or leased by others. The railroad owned hopper and gondola cars were, respectively, 93 and 100 percent in dedicated service; all of the other leased and owned cars were in dedicated service. However, only 19 percent of the trains had dedicated power. Maximum operating speeds ranged from 25-60 mph empty and 10-60 mph loaded.

2.5.2 Car Requirements. While the ownership data would seem to imply that the less specialized cars are left for non-railroad leasors and owners, the sheer numbers suggest that, particularly as the number of unit coal trains have accelerated recently, car and steel shortages may be a problem in future expansion.

The railroads have claimed that the shortage in hopper cars beginning in 1973 was at least partly due to accelerated scrapping schedules in 1972-3. At that time, due to a decline in coal traffic, a reported 25-30,000 car surplus existed. While of historic interest, this is not entirely germane. What counts is the ability of the railroads to obtain sufficient cars to haul anticipated coal. In this, hopper and gondola cars compete with backlog orders of other cars. This is true whether the cars are purchased (e.g., from Pullman-Standard and/or Bethlehem Steel) or are built in the railroads' own workshops. Given a three year build-up period (from 1976), recession or slow general growth (which slows orders for other cars), and the more than 17,850 new hopper cars delivered between January 1974 and August 1975, it does not appear that car shortages will be critical to coal development. Similarly, there does not appear to be a potential shortage of locomotives. Both numbers and horsepower have been increasing.

The total car situation, based on Association of American Railroads data for December 1, 1975, was as follows:

	Serviceable Owned	Heavy Bad Order	Total
Open Hopper	328403	13542	341945
Gondola	160132	13616	173748
Total	488535	27158	515693

Forecast needs for hopper and gondola cars have been estimated by the American Railway Car Institute, "Long-Term Freight Car Forecast, 1980/1985." Unfortunately, the estimates are based primarily on GNP assumptions rather than estimates of potential specific demand. For coal this is apt to lead to a low estimate. However, since the coal tonnage is supplied in the estimates, a handle on car needs with respect to other scenarios can be estimated. The study estimates that coal carried on Class I railroads was 396.0 MMT in 1974 and will be 555 MMT and 655 MMT (net) per year in 1980 and 1985, respectively. Recent FEA estimates for 1980 and 1985 are 799 MMT and 1039 MMT, respectively. The average capacity of hopper cars is expected to rise from 78.5 tons in 1974 to 90.0 tons in 1980 and 95.4 tons in 1985. The respective figures for gondola cars are: 80.1 tons, 88.5 tons, and 95.8 tons. This growth reflects primarily the scrapping of older smaller cars and replacement with the 100 ton variety. It does indicate that progressively more coal can be carried without proportionately lengthening trains or increasing the number of cars.

The 1975 adjusted age distribution of open hopper cars is reported to be 29 percent less than 10 years old, 39 percent 11-20 years old, 22 percent 21-30 years old, 9 percent 31-40 years old and 1 percent over 40 years old. Gondola cars show a similar distribution but with more cluster in the 21-30 year category. Thus, our cost estimates based on a 20-year retirement cycle is conservative (high cost) compared to practice. Of the 357,000 hopper cars forming the basis for the distribution, 82,000 are expected to be retired and/or destroyed between 1975 and 1980. A total of 94,000 more will be retired and destroyed from 1981-1985. Thus, of the 357,000 hopper cars, 49 percent will be permanently out of service by 1985. For gondola cars, the similar comparison is 187,000 cars initially with a total of 105,000 or 56 percent permanently out of service by 1985. To carry the same coal traffic, however, it should again be pointed out that increasing car size reduces the number of cars needed. Some forecast results for both open hopper and open gondola cars (both potential coal carriers) are provided in Table 2.6. Again it

Table 2.6

Estimated Car Requirements

	1974		1980		1985	
	H*	G**	H	G	H	G
Tons Originated (10^6)	612.3	197.9	780.1	224.4	891.0	237.6
Car Capacity (tons)	78.5	80.3	90.0	88.5	95.4	95.8
Load Factor (%)	96.3	82.3	95.0	85.5	95.0	90.8
Average Tons/Car	75.6	66.1	85.5	75.7	90.6	87.0
Serviceable Cars Required (000)	294	150	326	143	333	120
Actual Fleet (000)	357	187	363	169	392	141
Fleet Required (12/31/80 and 12/31/85) (000)			383.4	168.5	392.2	141.5
New Car Demand 1975/80, 1981/85 (000)			109.3	33.1	103.1	27.5
New Car Demand per year (000)			18.2	5.5	20.6	5.5
1980 and 1985 Forecasts (GNP basis)						
Low (000)			15.1	4.6	20.6	5.5
Control (000)			18.2	5.5	20.6	5.5
High (000)			22.2	6.7	21.4	5.7

*Hopper cars

**Gondola cars

Source: American Railway Car Institute, Long-Term Freight Car Forecast, 1980/1985 (1973).

must be noted that these estimates are GNP based. Additionally, they were developed in 1973. The above estimates were based on assumptions concerning retirements, the age distribution of the current fleet, load factors, size, utilization, prediction of 555 MTY and 655 MTY of coal moved in 1980 and 1985 respectively, and a mix of commodities which use gondolas and open hopper cars. As noted above, FEA estimates of coal produced in 1980 and 1985 are 799 MTY and 1039 MTY, respectively. Not all will be moved by rail. If we assume to be conservative (high) that 90 percent will be moved by rail, then coal rail movements will be 30 percent more in 1980 and 43 percent more in 1985 than those predictions which formed the basis for this estimate. If we further assume that all other uses of gondola and hopper cars are GNP based, that these were estimated correctly, and that they constitute 37 percent of the use of both types of cars in 1980 and 52 percent in 1995, then the estimated total of these cars used for coal in 1980 and 1985 based on the GNP estimates will be 347,700 and 256,200. The reduced number in 1985 reflects increased average car size, utilization and load factors. Inflating the coal fleet proportionately to meet the FEA estimates, suggest a fleet size for coal of 452,000 cars in 1980 and 366,400 in 1985. To this may be added 204,200 and 277,500 in each year, used for other service. This results in a required fleet estimate (gondolas and hoppers) of 20 percent more than the tabled estimate. Because retirements can be delayed, this need not be directly translated into new car demand forecasts.

2.5.1 Track Upgrading. In addition to car and locomotive requirements, resources will be required to upgrade and maintain the railroads. These have been noted in previous subsections. The diversity of railway track materials may be found in the Steel Products Manual of these materials published by the American Iron and Steel Institute (October 1975). The physical condition of the railroads was the subject of a recent (November 1975) study by U.S. Comptroller General, "Information Available on Estimated Costs to Rehabilitate the Nation's Railroad Track and a Summary of Federal Assistance to the Industry," *Report* to the Subcommittee on Federal Spending Practices, Efficiency, and Open Government, Committee on Government Operations, U.S. Senate. After reviewing recent studies by the Federal Railway Association, the Interstate Commerce Commission, the Association of American Railroads, and the U.S. Railway Association, it is concluded that, "No comprehensive studies existed which objectively and quantitatively described the existing condition of track on a nationwide basis. None of the available cost estimates to repair or replace deteriorated track provided a complete, reliable assessment of the long-term financial resources that might be required...". While the problem areas appear to be northeastern and midwestern, in general, to be done properly, the analysis must be on a system by system basis. To the extent that a given movement covers more than one system, an evaluation of condition must be made for all.

2.5.4 The Steel Interface. Between the forecast demand for new cars and the necessity of rail upgrading, a considerable burden will be placed on the steel industry. This is the subject of a current General Accounting Office study. The results should be available in 3-4 months. An earlier study (March 1975) prepared by the Association of American Railroads," Report on Steel in Relation to Railroad Needs," came to the following conclusions.

(1) Despite recent improvements in track and car deliveries, shortages exist in forgings, castings, plate and track materials.

(2) Locomotive parts and wheels are in particularly short supply.

(3) The five overage mills supplying track are particularly critical.

(4) Lead time status in 1975 had risen by 67 percent for freight car material (6.75 weeks normal average), by 121 percent for maintenance of right of way material (14.75 weeks normal average), and 105 percent for miscellaneous items (5.44 weeks normal average). Only locomotive material, 4.4 week normal average, remained constant.

(5) At least part of the problem is steel industry inputs. Another is erratic railroad demand.

(6) FEA Project Independence estimates of rail industry steel requirements by 1985 are 10.7 million tons, or about one third of the total amount needed for transportation alone. No shortages of hopper cars or locomotives are anticipated but particular parts may be in short supply.

(7) Competition among suppliers is low. There are two locomotive companies, three U.S. rail producers (plus two more embargoed Canadian producers), six domestic wheel sources, eighteen car companies (in addition to the ten railroads that build some of their own) and a large number of producers of foundry products, car and locomotive parts, and producers of miscellany.

The steel industry is not known for its speed, adaptability, or as the cutting edge of technology. Given the age of the industry, it is probable that environmental regulations will tend to reduce overall output over the short-term. While a slow growth in GNP would relieve some of the competitive demand for steel, it would also reduce the demand for railroad equipment, though not necessarily for coal carrying equipment. In the short-term, critical shortages, known in advance, could be handled by imports, though at a higher price. Furthermore, aluminum sided cars could spread the impact across two industries. These cars have been in service since 1960. They have a higher initial cost and, apparently, a shorter life. Against this must be placed their saving in weight. This can be translated into fuel savings which increase with distance, tons carried, and the increasing price of diesel oil. For average runs, the weight saving is in the order of 8-10 percent. Other savings can be achieved through standardization of specifications, negotiation with respect to standards and cooperative buying and demand forecasts.

2.5.5 Labor Requirements. Unit trains need not be crewed at the same level as general freight. An early study (4) pointed out the elimination of associated labor in yards, switching, accounting and administration. In addition they indicate potential crew change savings due to a reduction in trip time. The possibility of crew reduction from five members to total automation is also explored. Given the added costs required for safety equipment, this last seems improbable except on special, unimpeded, runs. However, a shift from 5 to 3 crew members per train crew does not appear unwarranted.

2.5.6 Environment. Noise, route density, dirt, land alienation, and aesthetics are the principal environmental hazards. Excluding aesthetics, we have accounted for both noise and route density by assuming double tracking and route diversion. This involves land alienation. The data are provided in earlier subsections. The range of land values may be inferred from Section I. It must be noted, however, that railroad utilization is total; pipelines and transmission lines have only easements. However, a railroad corridor could be used for other transport modes.

REFERENCES

Section II

1. Ferguson, A. J., "Unit Train Transportation of Coal," Appendix E of M. Rieber, S. L. Soo and J. Stukel, The Coal Future, University of Illinois at Urbana-Champaign, CAC Document No. 163, May 1975.

2. Soo, S. L. and L. Ballard, "Cost of Transportation of Coal: Rail vs. Slurry Pipeline," in Appendix F of M. Rieber, S. L. Soo and J. Stukel, The Coal Future, University of Illinois at Urbana-Champaign, CAC Document No. 163, May 1975.

3. U.S. Department of the Interior, Bureau of Mines, "Unit Train Transportation of Coal," IC 8444 (1970).

4. Railway Systems and Management Association, Unit Train Operations, January 1967.

APPENDIX SECTION 2

UNIT TRAINS

COSTS AND RESOURCES FOR UNIT TRAIN TRANSPORTATION

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[illegible]

[illegible]

[illegible]

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[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
TOTAL EMPLOYMENT	[illegible]

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TOTAL ANNUAL COST	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
TOTAL EMPLOYMENT	[illegible]

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TOTAL ANNUAL COST	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
TOTAL EMPLOYMENT	[illegible]

FULL CAPACITY OPERATION - SPEED [illegible] MPH LOADED, [illegible] MPH UNLOADED

NUMBER OF TRAINS [illegible]

CAPITAL COSTS	ANNUAL FIXED CHARGE [illegible]	OPERATING COSTS	UNIT COSTS	ENERGY REQUIREMENTS	STEEL REQUIRED	EMPLOYMENT
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL [illegible]	TOTAL [illegible]	TOTAL [illegible]			TOTAL [illegible]	TOTAL [illegible]
	TOTAL ANNUAL COST [illegible]				[illegible]	

[illegible] CHANGE IN OPERATION, SPEED [illegible]

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TOTAL ANNUAL COST	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
TOTAL EMPLOYMENT	[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

```
[illegible] CHANGE IN OPERATION ,SPEED [illegible]

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TOTAL ANNUAL COST           [illegible]
UNIT COST $/TON             [illegible]
UNIT COST $/TON-MILE        [illegible]
FUEL REQUIREMENTS [illegible] [illegible]
TOTAL EMPLOYMENT            [illegible]

[illegible] CHANGE IN OPERATION ,SPEED [illegible]

TOTAL OPERATING COST        [illegible]
TOTAL ANNUAL COST           [illegible]
UNIT COST $/TON             [illegible]
UNIT COST $/TON-MILE        [illegible]
FUEL REQUIREMENTS [illegible] [illegible]
TOTAL EMPLOYMENT            [illegible]

[illegible] CHANGE IN OPERATION ,SPEED [illegible]

TOTAL OPERATING COST        [illegible]
TOTAL ANNUAL COST           [illegible]
UNIT COST $/TON             [illegible]
UNIT COST $/TON-MILE        [illegible]
FUEL REQUIREMENTS [illegible] [illegible]
TOTAL EMPLOYMENT            [illegible]

[illegible] CHANGE IN OPERATION ,SPEED [illegible]

TOTAL OPERATING COST        [illegible]
TOTAL ANNUAL COST           [illegible]
UNIT COST $/TON             [illegible]
UNIT COST $/TON-MILE        [illegible]
FUEL REQUIREMENTS [illegible] [illegible]
TOTAL EMPLOYMENT            [illegible]

[illegible] CHANGE IN OPERATION ,SPEED [illegible]

TOTAL OPERATING COST        [illegible]
TOTAL ANNUAL COST           [illegible]
UNIT COST $/TON             [illegible]
UNIT COST $/TON-MILE        [illegible]
FUEL REQUIREMENTS [illegible] [illegible]
TOTAL EMPLOYMENT            [illegible]
```

FULL CAPACITY OPERATION - SPEED [illegible] MPH LOADED,[illegible] MPH UNLOADED

NUMBER OF TRAINS [illegible]

CAPITAL COSTS		ANNUAL FIXED CHARGE ON CAPITAL		OPERATING COSTS		UNIT COSTS	ENERGY REQUIREMENTS	STEEL REQUIRED	EMPLOYMENT
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		DEPRECIATION	[illegible]						
TOTAL	[illegible]	TOTAL	[illegible]	TOTAL	[illegible]			TOTAL [illegible]	TOTAL [illegible]
		TOTAL ANNUAL COST	[illegible]					[illegible]	

[illegible] CHANGE IN OPERATION ,SPEED [illegible] MPH

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST [illegible] [illegible]
UNIT COST [illegible] [illegible]
FUEL REQUIREMENTS [illegible] [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible] CHANGE IN OPERATION ,SPEED [illegible] MPH

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST [illegible] [illegible]
UNIT COST [illegible] [illegible]
FUEL REQUIREMENTS [illegible] [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible] CHANGE IN OPERATION ,SPEED [illegible] MPH

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST [illegible] [illegible]
UNIT COST [illegible] [illegible]
FUEL REQUIREMENTS [illegible] [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible] CHANGE IN OPERATION ,SPEED [illegible] MPH

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST [illegible] [illegible]
UNIT COST [illegible] [illegible]
FUEL REQUIREMENTS [illegible] [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible] CHANGE IN OPERATION ,SPEED [illegible] MPH

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST $/TON [illegible]
UNIT COST $/TON-MILE [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

FULL CAPACITY OPERATION - SPEED [illegible] MPH LOADED,[illegible] MPH UNLOADED

NUMBER OF TRAINS [illegible]

CAPITAL COSTS	ANNUAL CHARGE ON DEBT	OPERATING COSTS	UNIT COSTS	ENERGY REQUIREMENTS	STEEL REQUIRED	EMPLOYMENT
[illegible]	[illegible]	FUEL [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	LABOR [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
EQUIP. [illegible]	[illegible]	SUPPLY [illegible]	[illegible]		[illegible]	[illegible]
	DEPRECIATION [illegible]					
TOTAL [illegible]	TOTAL [illegible]	TOTAL [illegible]			TOTAL [illegible]	TOTAL [illegible]
	TOTAL ANNUAL COST [illegible]				CONCRETE [illegible] TIMBER [illegible]	

[illegible] CHANGE IN OPERATION ,SPEED [illegible] MPH

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST $/TON [illegible]
UNIT COST $/TON-MILE [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible] CHANGE IN OPERATION ,SPEED [illegible] MPH

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST $/TON [illegible]
UNIT COST $/TON-MILE [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible] CHANGE IN OPERATION ,SPEED [illegible] MPH

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST $/TON [illegible]
UNIT COST $/TON-MILE [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible] CHANGE IN OPERATION ,SPEED [illegible]

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TOTAL ANNUAL COST [illegible]
UNIT COST $/TON [illegible]
UNIT COST $/TON-MILE [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible] CHANGE IN OPERATION ,SPEED [illegible]

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST $/TON [illegible]
UNIT COST $/TON-MILE [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

COSTS AND RESOURCES FOR UNIT TRAIN TRANSPORTATION

MILLION DOLLARS - 25 MMTY

ROUTE = 2, GILLETTE - CHICAGO [illegible] MILES

FULL CAPACITY OPERATION - SPEED [illegible] MPH LOADED,[illegible] MPH UNLOADED

NUMBER OF TRAINS [illegible]

CAPITAL COSTS	ANNUAL FIXED CHARGE ON PLANT	OPERATING COSTS	UNIT COSTS	ENERGY REQUIREMENTS	STEEL REQUIRED	EMPLOYMENT
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL [illegible]	TOTAL [illegible]	TOTAL [illegible]			TOTAL [illegible]	TOTAL [illegible]
	TOTAL ANNUAL COST [illegible]				[illegible]	

[illegible] CHANGE IN OPERATION ,SPEED [illegible]

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TOTAL ANNUAL COST [illegible]
UNIT COST $/TON [illegible]
UNIT COST $/TON-MILE [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

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TOTAL ANNUAL COST         [illegible]
UNIT COST [illegible]     [illegible]
UNIT COST [illegible]     [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT          [illegible]

[illegible] CHANGE IN OPERATING SPEED [illegible]

TOTAL OPERATING COST      [illegible]
TOTAL ANNUAL COST         [illegible]
UNIT COST [illegible]     [illegible]
UNIT COST [illegible]     [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT          [illegible]

[illegible] CHANGE IN OPERATING SPEED [illegible]

TOTAL OPERATING COST      [illegible]
TOTAL ANNUAL COST         [illegible]
UNIT COST [illegible]     [illegible]
UNIT COST [illegible]     [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT          [illegible]

[illegible] CHANGE IN OPERATING SPEED [illegible]

TOTAL OPERATING COST      [illegible]
TOTAL ANNUAL COST         [illegible]
UNIT COST [illegible]     [illegible]
UNIT COST [illegible]     [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT          [illegible]
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[illegible]

[illegible] CHANGE IN OPERATION ,SPEED [illegible]

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST RATIO [illegible]
UNIT COST [illegible] [illegible]
FUEL REQUIREMENTS [illegible] [illegible]
TOTAL EMPLOYMENT [illegible]

FULL CAPACITY OPERATION - SPEED [illegible]

NUMBER OF TRAINS [illegible]

CAPITAL COSTS	ANNUAL COSTS	OPERATING COSTS	UNIT COSTS	ENERGY REQUIREMENTS	STEEL REQUIRED	EMPLOYMENT
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL [illegible]	TOTAL [illegible]	TOTAL [illegible]			TOTAL [illegible]	TOTAL [illegible]
	TOTAL ANNUAL COST [illegible]				[illegible]	

[illegible] CHANGE IN OPERATION ,SPEED [illegible]

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST RATIO [illegible]
UNIT COST [illegible] [illegible]
FUEL REQUIREMENTS [illegible] [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible] CHANGE IN OPERATION ,SPEED [illegible]

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST RATIO [illegible]
UNIT COST [illegible] [illegible]
FUEL REQUIREMENTS [illegible] [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible] CHANGE IN OPERATION ,SPEED [illegible] MPH

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST $/TON [illegible]
UNIT COST $/TON-MILE [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible] CHANGE IN OPERATION ,SPEED [illegible] MPH

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST $/TON [illegible]
UNIT COST $/TON-MILE [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible] CHANGE IN OPERATION ,SPEED [illegible] MPH

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST $/TON [illegible]
UNIT COST $/TON-MILE [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

FULL CAPACITY OPERATION - SPEED [illegible] MPH [illegible]

NUMBER OF TRAINS [illegible]

CAPITAL COSTS	ANNUAL FIXED CHARGE	OPERATING COSTS	UNIT COSTS	ENERGY REQUIREMENTS	STEEL REQUIRED	EMPLOYMENT
[illegible]	[illegible]	FUEL [illegible]	[illegible]	[illegible]	CARS [illegible]	[illegible]
[illegible]	[illegible]	LABOR [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
EQUIP. [illegible]	[illegible]	SUPPLY [illegible]	[illegible]		RAIL [illegible]	[illegible]
	DEPRECIATION [illegible]					
TOTAL [illegible]	TOTAL [illegible]	TOTAL [illegible]			TOTAL [illegible]	TOTAL [illegible]
	TOTAL ANNUAL COST [illegible]				[illegible]	

[illegible] CHANGE IN OPERATION ,SPEED [illegible] MPH

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST $/TON [illegible]
UNIT COST $/TON-MILE [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

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        [illegible] CHANGE IN OPERATION ,SPEED [illegible]

TOTAL OPERATING COST       [illegible]
TOTAL ANNUAL COST          [illegible]
UNIT COST $/TON            [illegible]
UNIT COST $/TON-MILE       [illegible]
FUEL REQUIREMENTS  [illegible]
TOTAL EMPLOYMENT           [illegible]

        [illegible] CHANGE IN OPERATION ,SPEED [illegible]

TOTAL OPERATING COST       [illegible]
TOTAL ANNUAL COST          [illegible]
UNIT COST $/TON            [illegible]
UNIT COST $/TON-MILE       [illegible]
FUEL REQUIREMENTS  [illegible]
TOTAL EMPLOYMENT           [illegible]

        [illegible] CHANGE IN OPERATION ,SPEED [illegible]

TOTAL OPERATING COST       [illegible]
TOTAL ANNUAL COST          [illegible]
UNIT COST $/TON            [illegible]
UNIT COST $/TON-MILE       [illegible]
FUEL REQUIREMENTS  [illegible]
TOTAL EMPLOYMENT           [illegible]

        [illegible] CHANGE IN OPERATION ,SPEED [illegible]

TOTAL OPERATING COST       [illegible]
TOTAL ANNUAL COST          [illegible]
UNIT COST $/TON            [illegible]
UNIT COST $/TON-MILE       [illegible]
FUEL REQUIREMENTS  [illegible]
TOTAL EMPLOYMENT           [illegible]

     FULL CAPACITY OPERATION - SPEED [illegible] MPH LOADED,[illegible] MPH UNLOADED

                         NUMBER OF TRAINS [illegible]
-----------------------------------------------------------------------------------------
CAPITAL COSTS: ANNUAL FIXED    :OPERATING COSTS: UNIT COSTS :    ENERGY    : STEEL REQUIRED : EMPLOYMENT :
             : CHARGE ON DEBT  :               :            : REQUIREMENTS :                :            :
-----------------------------------------------------------------------------------------
[illegible]
-----------------------------------------------------------------------------------------
TOTAL  [illegible] : TOTAL  [illegible] : TOTAL  [illegible] :  :  : TOTAL [illegible] : TOTAL [illegible]
-----------------------------------------------------------------------------------------
             :        TOTAL ANNUAL COST  171,5  :          :          : [illegible]
-----------------------------------------------------------------------------------------
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               -20,0% CHANGE IN OPERATION ,SPEED 50,0+60, M/H

TOTAL OPERATING COST     84,8
TOTAL ANNUAL COST       159,6
UNIT COST $/TON          7,78
UNIT COST $/TON-MILE     4,21
FUEL REQUIREMENTS  1,33 [illegible]
TOTAL EMPLOYMENT         3212

               +40,0% CHANGE IN OPERATION ,SPEED 50,0+60, M/H

TOTAL OPERATING COST     51,5
TOTAL ANNUAL COST       144,7
UNIT COST $/TON          6,56
UNIT COST $/TON-MILE     3,45
FUEL REQUIREMENTS  1,70 [illegible]
TOTAL EMPLOYMENT         2634

               +47,0% CHANGE IN OPERATION ,SPEED 50,0+60, M/H

TOTAL OPERATING COST     36,5
TOTAL ANNUAL COST       123,1
UNIT COST $/TON         12,21
UNIT COST $/TON-MILE     1,11
FUEL REQUIREMENTS  4,64 [illegible]
TOTAL EMPLOYMENT         1876

                20,0% CHANGE IN OPERATION ,SPEED 50,0+60, M/H

TOTAL OPERATING COST     98,1
TOTAL ANNUAL COST       175,4
UNIT COST $/TON          8,50
UNIT COST $/TON-MILE     2,50
FUEL REQUIREMENTS  1,48 [illegible]
TOTAL EMPLOYMENT         4740

                40,0% CHANGE IN OPERATION ,SPEED 50,0+60, M/H

TOTAL OPERATING COST    118,5
TOTAL ANNUAL COST       241,3
UNIT COST $/TON          7,18
UNIT COST $/TON-MILE     2,68
FUEL REQUIREMENTS  2,57 [illegible]
TOTAL EMPLOYMENT         5670
```

FULL CAPACITY OPERATION - SPEED [illegible] MPH [illegible]

NUMBER OF TRAINS [illegible]

CAPITAL COSTS		ANNUAL FIXED CHARGE IN YEAR		OPERATING COSTS		UNIT COSTS	ENERGY REQUIREMENTS	STEEL REQUIRED		EMPLOYMENT	
TRUCKS	[illegible]	[illegible]	[illegible]	FUEL	[illegible]	[illegible]	[illegible]	CARS	[illegible]	[illegible]	[illegible]
ROADBED	[illegible]	[illegible]	[illegible]	LABOR	[illegible]	[illegible]	[illegible]	LOCO.	[illegible]	[illegible]	[illegible]
EQUIP.	[illegible]	[illegible]	[illegible]	SUPPLY	[illegible]	[illegible]	[illegible]	RAIL	[illegible]	[illegible]	[illegible]
		DEPRECIATION	[illegible]								
TOTAL	[illegible]	TOTAL	[illegible]	TOTAL	[illegible]			TOTAL	[illegible]	TOTAL	[illegible]
		TOTAL ANNUAL COST	[illegible]					CONCRETE	[illegible]		
								TIMBER	[illegible]		

[illegible] CHANGE IN OPERATION ,SPEED [illegible] MPH

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST $/TON [illegible]
UNIT COST $/TON-MILE [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible] CHANGE IN OPERATION ,SPEED [illegible] MPH

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST $/TON [illegible]
UNIT COST $/TON-MILE [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible] CHANGE IN OPERATION ,SPEED [illegible] MPH

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST $/TON [illegible]
UNIT COST $/TON-MILE [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible] CHANGE IN OPERATION ,SPEED [illegible] MPH

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST $/TON [illegible]
UNIT COST $/TON-MILE [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible] CHANGE IN OPERATION ,SPEED [illegible] MPH, [illegible]

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST $/TON [illegible]
UNIT COST $/TON-MILE [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible] CHANGE IN OPERATION ,SPEED [illegible] MPH, [illegible]

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST $/TON [illegible]
UNIT COST $/TON-MILE [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible] CHANGE IN OPERATION ,SPEED [illegible] MPH, [illegible]

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST $/TON [illegible]
UNIT COST $/TON-MILE [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

FULL CAPACITY OPERATION - SPEED [illegible] MPH [illegible]

NUMBER OF TRAINS [illegible]

CAPITAL COSTS	ANNUAL FIXED CHARGE ON CAPITAL	OPERATING COSTS	UNIT COSTS	ENERGY REQUIREMENTS	TOTAL MILEAGE	EMPLOYMENT
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL [illegible]	TOTAL [illegible]	TOTAL [illegible]			TOTAL [illegible]	TOTAL [illegible]
	TOTAL ANNUAL COST [illegible]				[illegible]	

[illegible] CHANGE IN OPERATION ,SPEED [illegible] MPH, [illegible]

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST $/TON [illegible]
UNIT COST $/TON-MILE [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

FULL CAPACITY OPERATION [illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]			[illegible]	[illegible]
	[illegible]				[illegible]	

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible] CHANGE IN OPERATION, SPEED [illegible], MPH

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST [illegible]
UNIT COST [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible] CHANGE IN OPERATION, SPEED [illegible], MPH

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST [illegible]
UNIT COST [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

FULL CAPACITY OPERATION - SPEED [illegible] MPH [illegible]

NUMBER OF TRUCKS [illegible]

CAPITAL COSTS	ANNUAL FIXED CHARGE [illegible]	OPERATING COSTS	UNIT COSTS	ENERGY REQUIREMENTS	STEEL REQUIRED	EMPLOYMENT
TRUCKS [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
EQUIP. [illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
	[illegible]				[illegible]	[illegible]
TOTAL [illegible]	TOTAL [illegible]	TOTAL [illegible]			TOTAL [illegible]	TOTAL [illegible]
	TOTAL ANNUAL COST [illegible]				[illegible]	

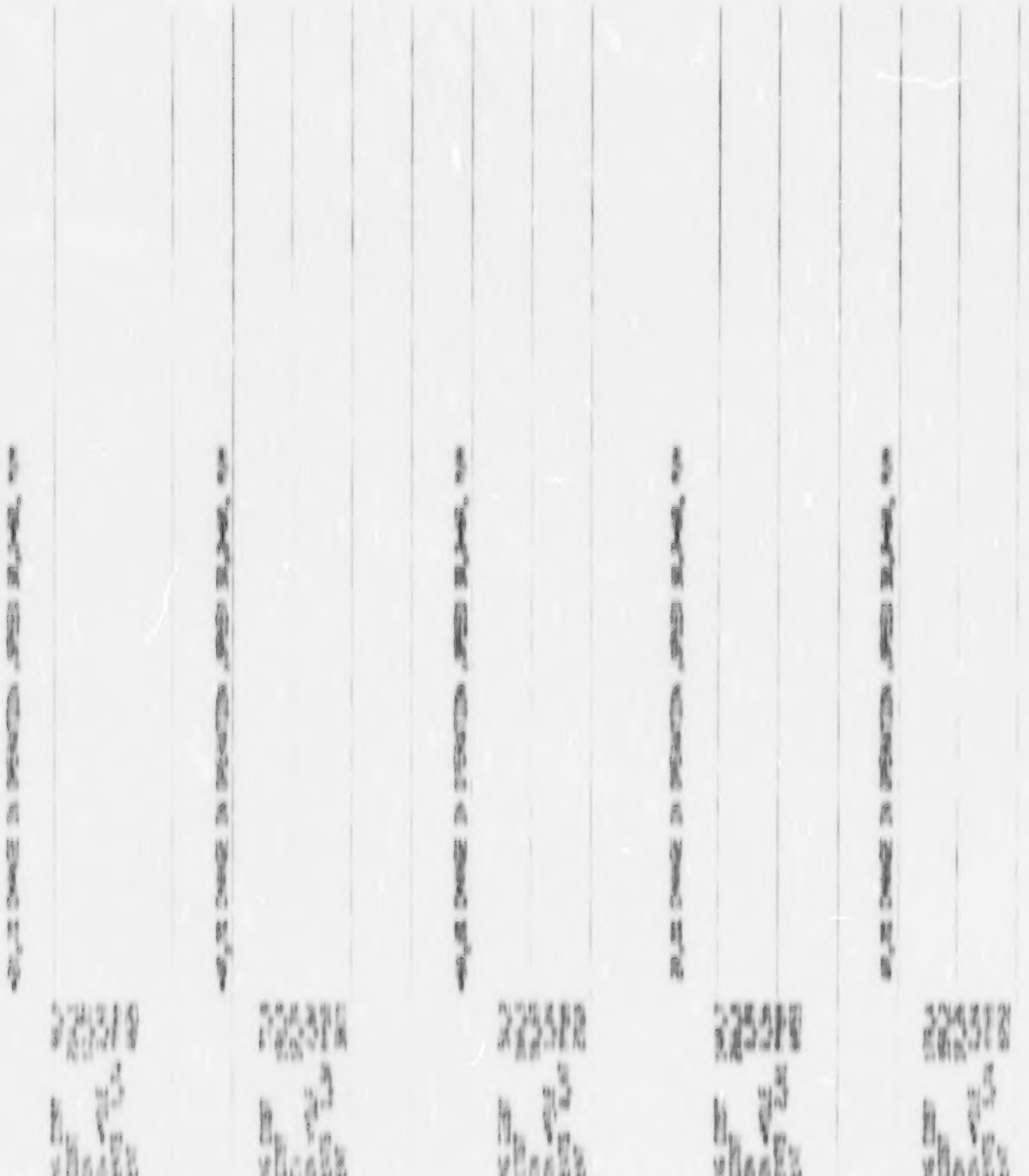
[illegible] CHANGE IN OPERATION, SPEED [illegible], MPH

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST [illegible]
UNIT COST [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible] CHANGE IN OPERATION, SPEED [illegible], MPH

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST [illegible]
UNIT COST [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible]



[illegible]

[illegible] CHANGE IN OPERATION SPEED [illegible]

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST [illegible]
UNIT COST [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

FULL CAPACITY OPERATION - SPEED [illegible]

NUMBER OF TRUCKS [illegible]

CAPITAL COSTS	ANNUAL FIXED CHARGE [illegible]	OPERATING COSTS	UNIT COSTS	ENERGY REQUIREMENTS	TOTAL [illegible]	EMPLOYMENT
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL [illegible]	TOTAL [illegible]	TOTAL [illegible]			[illegible]	TOTAL [illegible]
	TOTAL ANNUAL COST [illegible]				[illegible]	

[illegible] CHANGE IN OPERATION SPEED [illegible]

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST [illegible]
UNIT COST [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible] CHANGE IN OPERATION SPEED [illegible]

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST [illegible]
UNIT COST [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible] CHANGE IN OPERATION SPEED [illegible]

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST [illegible]
UNIT COST [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible]

[illegible]

[illegible]

COSTS AND RESOURCES FOR UNIT TRAIN TRANSPORTATION

[illegible]

[illegible]

[illegible]

[illegible]

CAPITAL COSTS	ANNUAL FIXED CHARGES	OPERATING COSTS	UNIT COSTS	ENERGY REQUIREMENTS	STEEL REQUIRED	EMPLOYMENT
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL [illegible]	TOTAL [illegible]	TOTAL [illegible]			TOTAL [illegible]	TOTAL [illegible]
	TOTAL ANNUAL COST [illegible]				[illegible]	

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

CAPITAL COSTS	ANNUAL COSTS CHANGE IN TIME	OPERATING COSTS	UNIT COSTS	ENERGY REQUIREMENTS	STEEL REQUIRED	EMPLOYMENT
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL [illegible]	TOTAL [illegible]	TOTAL [illegible]	[illegible]		TOTAL [illegible]	TOTAL [illegible]
	TOTAL ANNUAL COST [illegible]				[illegible]	

[illegible]

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST [illegible]
UNIT COST [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible]

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST [illegible]
UNIT COST [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible]

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST [illegible]
UNIT COST [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible]

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST [illegible]
UNIT COST [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible]

[illegible] CHANGE IN OPERATION [illegible]

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST RATIO [illegible]
UNIT COST [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible] CHANGE IN OPERATION [illegible]

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST RATIO [illegible]
UNIT COST [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

COSTS AND RESOURCES FOR UNIT TRAIN TRANSPORTATION

MILLION DOLLARS - 25 [illegible]

ROUTE [illegible] GILLETTE - NEW YORK [illegible] MILES

FULL CAPACITY OPERATION - SPEED [illegible]

NUMBER OF TRAINS [illegible]

CAPITAL COSTS	ANNUAL FIXED CHARGE ON CAP	OPERATING COSTS	UNIT COSTS	ENERGY REQUIREMENTS	STEEL REQUIRED	EMPLOYMENT
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL [illegible]	TOTAL [illegible]	TOTAL [illegible]			TOTAL [illegible]	TOTAL [illegible]
	TOTAL ANNUAL COST [illegible]				[illegible]	

[illegible] CHANGE IN OPERATION [illegible]

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST RATIO [illegible]
UNIT COST [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible] CHANGE IN OPERATION, SPEED [illegible] MPH

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
[illegible]
[illegible]
[illegible]
TOTAL EMPLOYMENT [illegible]

[illegible] CHANGE IN OPERATION, SPEED [illegible] MPH

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
[illegible]
[illegible]
[illegible]
TOTAL EMPLOYMENT [illegible]

[illegible] CHANGE IN OPERATION, SPEED [illegible] MPH

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
[illegible]
[illegible]
[illegible]
TOTAL EMPLOYMENT [illegible]

[illegible] CHANGE IN OPERATION, SPEED [illegible] MPH

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
[illegible]
[illegible]
[illegible]
TOTAL EMPLOYMENT [illegible]

FULL CAPACITY OPERATION - SPEED [illegible] MPH LOADED, [illegible] MPH UNLOADED

NUMBER OF TRAINS [illegible]

CAPITAL COSTS	ANNUAL FIXED CHARGE [illegible]	OPERATING COSTS	UNIT COSTS	ENERGY REQUIREMENTS	STEEL REQUIRED	EMPLOYMENT
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL [illegible]	TOTAL [illegible]	TOTAL [illegible]			TOTAL [illegible]	TOTAL [illegible]
	TOTAL ANNUAL COST [illegible]				[illegible]	

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

125

[illegible] CHANGE IN OPERATION ,SPEED [illegible] MPH

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST $/TON [illegible]
UNIT COST $/TON-MILE [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible] CHANGE IN OPERATION ,SPEED [illegible] MPH

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST $/TON [illegible]
UNIT COST $/TON-MILE [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible] CHANGE IN OPERATION ,SPEED [illegible] MPH

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST $/TON [illegible]
UNIT COST $/TON-MILE [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

FULL CAPACITY OPERATION - SPEED [illegible] MPH LOADED,[illegible] MPH UNLOADED

NUMBER OF TRUCKS [illegible]

CAPITAL COSTS	ANNUAL FIXED CHARGE [illegible] YEAR	OPERATING COSTS	UNIT COSTS	ENERGY REQUIREMENTS	STEEL REQUIRED	EMPLOYMENT
TRUCKS [illegible] TRAILERS [illegible] EQUIP. [illegible]	[illegible] [illegible] [illegible] DEPRECIATION [illegible]	FUEL [illegible] LABOR [illegible] SUPPLY [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TOTAL [illegible]	TOTAL [illegible]	TOTAL [illegible]			TOTAL [illegible]	TOTAL [illegible]
	TOTAL ANNUAL COST [illegible]				[illegible]	

[illegible] CHANGE IN OPERATION ,SPEED [illegible] MPH

TOTAL OPERATING COST [illegible]
TOTAL ANNUAL COST [illegible]
UNIT COST $/TON [illegible]
UNIT COST $/TON-MILE [illegible]
FUEL REQUIREMENTS [illegible]
TOTAL EMPLOYMENT [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

SECTION III

COAL SLURRY PIPELINES

3.1 General.

Slurry pipelines are less route specific than railroads. Terrain is relatively unimportant in terms of pumping distance, but the terrain affects the cost of construction, the pipeline operating pressure, and the pumping power required; greater distance might have to be tolerated to avoid extremes in the other parameters. Existing pipelines do not return the water to the origin after dewatering at the receiving end. Thus, the availability, and to a lesser extent, the cost of water can be a problem. Evaporation of the water after dewatering by feeding into cooling towers can also be a problem since 1.7 tons/day of coal fines might be released to the atmosphere for a shipment of 25 MMTY. No control has been considered by ETSI. If the coal transported is to be exported after dewatering, this water will lack evaporation facilities. Returning the water by pumping it back to the mine area after adding the make-up water means an added cost of piping and pumping but solves the problem of water availability. The condition under which returning the water to the mine area is justifiable is one of the terms analysed in this study. It was shown in our earlier study that slurry pipeline is superior if new railroad must be built for shipping coal alone over a distance of shipment of more than about 200 miles.

The lack of flexibility in economic shipping capacity is an important feature of the slurry pipeline. A line designed for 3.5 mph flow velocity cannot be safely operated at a velocity below 3 mph without plugging. Operation at 5 mph requires a design providing for double the horsepower, peak pressure, and wear.

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The capital costs of a slurry line are completely front ended. A 7 percent escalation of cost is used as an average, although 4 percent was proposed by ETSI in view of the low operating labor component. Given maintenance, repair, partial replacement and possible plugging, the labor component may not be the proper criterion.

The cost per unit commodity capacity mile at reduced capacity increases by the inverse of the fraction of full load; an 80 percent load factor increases the unit cost by 25 percent. The upper limit of capacity is usually the safest and most economic operating condition for a slurry pipeline. A part load in a slurry pipeline is not feasible although a line designed for 5 mph operation can be operated at 3.5 mph though at much higher unit cost. A slurry line can be branched if there is steady flow at both the inlet and the delivery points, but variables dispatching is not feasible because the trunk lines have to be operated within a narrow speed range. Delivery points and inlet points can be switched following a rigid schedule but cannot be tapped and fed at will. A stopped line can be flushed with water, but trunk line flow cannot be fed through, say, one of 5 branch lines with arbitrary closing off of the others.

A number of falacies concerning the slurry pipeline have been propagated on both sides of the argument. A listing based on facts and experience, is desirable. The ideas to be covered include the following:

(1) The statement that the Black Mesa line uses 10.4 MMCFD of gas for coal drying and flame stabilization for 4.8 MTY is untrue. That allegation assumes the use of gas for drying coal rather than mechanical dewatering.

(2) Two hundred mesh coal in the slurry may settle out in 36 hours. This is the confidence limit for stopping the line without flushing.

(3) The output slurry is to be stored in holding tanks with continuous stirring.

(4) The abrasion and wear on pipes is nearly uniform because of the density of water. Design safety factors include provision against line break.

(5) Short term shut downs of less than 3 days have been shown to be allowable.

(6) Low points are to be avoided whenever possible. Stream crossings are best handled by overground pipes.

(7) Pipe cost is proportional to 0.65 power of the pipe diameter. Based on unit flow throughput small pipes cost more in both material and pumping power.

(8) Distribution lines should follow the above formula.

(9) More water is not needed for branching but rigid requirements of operation is a real problem.

3.2 Capital Cost Elements.

The pipeline routes specified in Section 1.1 are given in detail in Table 3.1 which shows for each route the number of miles for the shortest practical route for each

Table 3.1

COAL SLURRY PIPELINE ROUTES

Slurry Pipeline:

(1) Farmington, NM to Los Angeles, CA
M = 660 Miles HV = 10080
W/O & W/ return water
Water cost, W = 1, 2.50 $/gallon
3 cases.

(2) Gillette, WY to Chicago, IL
M = 1000 Miles HV = 10080
W/O & W/ return water
Water cost, W = 1, 2.50 $/gallon
3 cases.

(3) Gillette, WY to Houston, TX
M = 1210 Miles HV = 10080
W/O & W/ return water
Water cost, W = 1, 2.50 $/gallon
3 cases.

(4) Colstrip, MT to Seattle, WA
M = 840 Miles HV = 10080
W/O & W/ return water
Water cost, W = 1, 2.50 $/gallon
3 cases.

given topography. This gives rise to the curvature of the pipelines shown in Figure 1.1, although there are fewer twists and turns than for rails, giving the pipeline an advantage in westward shipments.

The different nature of the coal slurry line from crude oil pipelines renders cost estimates based on crude oil lines too low. The ETSI data for 1974, when escalated at 7 percent is 13 percent higher than 1975 crude oil pipeline data because of significantly different pumping facilities.

The costs of preparation equipment and wells, the pipeline and pumping stations, and the dewatering facilities for the Black Mesa pipeline (5 MMTY) as well as for the Wyoming to Arkansas pipeline (25 MMTY), based on ETSI estimates, are escalated to produce 1975 prices and to show the details of capital costs. Additional details are given in the notes to items in Table 3.2. Next, additional assumptions concerning capital cost estimates are noted.

One caveat must be noted. When a private line is built it is often impossible to say how much of the capital cost (if any) has been absorbed by the companies at either end and not debited to the pipeline. Similarly, shipment costs become akin to transfer prices. The strict analogy is that between the "costs" of company owned oil tankers and those chartered on the open market (not spot rates). There is no unique connection between the two. The Black Mesa line fits this description.

The Black Mesa pipeline consists of one mine supplying one destination by a 273 mile, 18 inch pipeline. It supplies 5 million tons of coal per year to the Mohave Generating Station. A 38 inch Wyoming to Arkansas pipeline of 1,040 miles would supply 25 million tons of coal per year. More than one mine will be needed to provide the 25 million tons of coal. Five with coal preparation facilities like

Table 3.2

ITEMIZED CAPITAL COSTS OF BLACK MESA AND WYOMING-ARKANSAS COAL SLURRY PIPELINES

	Preparation	Black Mesa 273 miles 5×10^6 tons/yr		Wyoming-Arkansas 1,040 miles 25×10^6 tons/yr
1.	Transport from mine	1.5		7.5
2.	Truck hopper	0.05		0.25
3.	Initial crushing and cleaning	1.0		5.0
4.	Stocking conveyor	0.2		1.0
5.	In-active storage	1.0		5.0
6.	Raw storage	0.68		3.4
7.	Active storage	1.0		5.0
8.	Dozers and scrapers	0.6		3.0
9.	Conveyor transfer tower	0.2		1.0
10.	Transfer tower	0.3		1.5
11.	Conveyor to bunkers	0.15		0.75
12.	Bunkers and feeders	0.15		0.75
13.	Operating plant	1.0		5.0
14.	Vibrator	0.2		1.0
15.	Impactor	0.5		2.5
16.	Rod mill	1.5		7.5
17.	Vibrator	0.15		0.75
18.	Slurry holding tank	0.6		3.0
19.	Slurry test loop	0.05		0.25
20.	Land	0.05		0.25
21.	Wells and water pumps	1.25		6.25
22.	Water working storage	0.35		1.75
23.	Water reservoir and pipe	0.3		1.5
24.	Water piping and rust inhibitor injectors	0.1		0.5
25.	First pumping station	5.0		25.0
	TOTAL: Preparation	17.88		89.4
	Pipeline			
26(a)	Mainline	45.6	26(b)	700
27.	Collecting and branch lines			190
28(a)	Coal in pipelines	0.23	28(b)	4.4
	TOTAL: Pipeline	45.83		894.4

Table 3.2 Continued

	Separation	Black Mesa 273 miles 5×10^6 tons/yr		Wyoming-Arkansas 1,040 miles 25×10^6 tons/yr
29(a)	Permanent storage	4.8	29(b)	13.0
30.	Holding tanks	2.1		10.5
31.	Dewatering centrifuges	4.0		18
32.	Pulverizers	0.9		4.5
33.	Flocculating tanks	0.7		3.5
34.	Piping	0.15		0.75
	TOTAL: Separation ----------------	12.65	----------	50.25
	TOTAL CAPITAL COST ----------------	76.36	----------	1034.0

Notes to Table 3.2:

1. Five 125-ton trucks for transport from the mine @ $30,000 each.
2. Truck hopper @ $50,000
3. Two 20 ft by 14 ft diameter rotary breakers, $1,000/ton/hr x 660 ton/hr x 1.5 [4a]
4. Movable stacking conveyor, $800/ft x 250 ft [4b]
5. 200,000 tons coal @ $5/ton in-active storage
6. 35,000 tons coal @ $5/ton raw storage + feeder and site development @ $500,000 [4c,5]
7. 36,000 tons coal @ $5/ton active storage + rotary plow, structure above, and site development @ $810,000 [4c,5]
8. Four bulldozers or scrapers @ $150,000
9. 400 ft by 30 in. conveyor, $250/ft equipment x 400 ft x 1.28 labor and material/material x 1.6 [4d,6a]
10. Transfer tower with 300 ton bin; coal sampler and weigher @ $300,000
11. 300 ft x 30 in. conveyor, $250/ft equipment x 300 ft x 1.28 labor and material/materials x 1.6 [4d,6a]
12. Three 590 ton bunkers with feeders @ $50,000
13. Operating plant @ $1,000,000
14. Three 6 ft x 10 ft twindeck vibrators, 3 x $1,100/$ft^2$ x $60^{0.58}$ ft^2 x 1.32 installation x 2.4 stainless steel x 1.5 [6a]
15. Three impactors, 290 tons/hr, 3 x $85/ton/hr x $290^{1.2}$ tons/hr x 1.57 installation x 1.5 [6a]
16. Three 18 ft x 13 ft I.D. rod mills, 1,500 hp, 150 tons of rods, 3(150 tons x 2,000 lb x $1/lb + $20,000/motor x 8.5 installation) [7,8]
17. Three 3.5 ft x 4 ft wedge wire screen vibrator, 3 x $900/$ft^2$ x $14^{0.58}$/ft^2 x 1.32 installation x 2.4 stainless steel x 3 wedge wire x 1.5 [6a]

Table 3.2 Continued

18. Four 650,000 gallon tanks with 10 ft 125 hp agitator, 4($60,000/tank x 1.75 inflation + $350/hp x 125$^{0.5}$ hp x 1.62 installation x 1.5 inflation) + $100,000 slurry tower
19. 206 ft test loop, 4,200 gpm @ $50,000
20. 100 acres @ $500/acre
21. Five 3,400 ft wells and pumps @ $250,000 [9]
22. 150 ft diameter x 48 ft high, 6.3 x 10^{6} gal water storage tank, $200,000 x 1.75 [6b]
23. 3 x 10^{6} gal plastic lined tank and 14 in., two-mile pipe, $150,000 x 1.75 + $40,000 pipe [6b]
24. Piping and rust inhibitor injectors @ $150,000
25. Three 1,750 hp, 330 tons/hr coal equivalent slurry pumps, 1,000 psi discharge, 3 x $1,330,900 + $1,000,000 accessories [6c]
26a. $7,120,000 pumping x 5 x 10^{6} tons/9 x 10^{6} tons x 1.65 inflation + $17,590,000 mainline x 273 miles/344 miles x 5 x 10^{6}/9 x 10^{6} tons x 2.1 inflation = $5,000,000 first pumping station [10]
26b. ($13,000,000 + $3,400,000) x 5 pipeline valuation in Niobrara and Goshen Counties, Wyoming, x 1,340 miles/106 miles x 0.91 deflation = $25,000,000, first pumping station [9]
27. ($20,800,000 + 3,600,000) x 5 collecting pipeline valuation in Campbell and Converse Counties, Wyoming, x 2 destination supply lines as well as collecting lines x 0.91 deflation [9]
28a. 46,000 tons coal in pipe @ $5/ton
28b. 875,000 tons coal in pipe @ $5/ton
29a. Two 36 x 10^{6} gal storage tanks in a ground plastic lined, 90 tons coal each, 2($200,000 for 6 x 10^{6} gal tank item 22 x 6$^{0.8}$ size factor x 1.75 inflation + 90,000 tons coal x $10/ton) [6b,8]
29b. 1 x 10^{6} tons coal hauled by train and stored dry @ $10/ton + $3,000,000 for facilities
30. Three 6 x 10^{6} gal holding tanks, 15,500 tons of coal, 3($200,000/tank x 1.75 inflation + $200,000 agitator and accessories + 15,500 tons x $10/ton) [6b,8]
31. Twenty centrifuges, 20 x $35,000/centrifuge x 3.1 process plant cost ratio x 1.9 [8,11b]
32. Ten pulverizers, $520/lb x (660 tons/hr x 2,000 lb/ton)0.35 x 1.59 installation x 1.8 [6a]
33. Two 200 ft I.D. tanks @ $350,000 [6b]
34. Piping @ $150,000

Black Mesas are assumed. Five destinations are also assumed because the Mojave Generating Station is the largest coal-burning facility in the United States with a daily consumption of 25,000 tons (9 million tons per year)[2].

The assumptions for coal preparation capital costs are for Black Mesa. About five times that amount would be required for the Wyoming-Arkansas pipeline. This linear extrapolation is also assumed for the costing of separation facilities because the pipeline can supply several power stations. Additionally, linear extrapolation is used because the largest equipment available was used at Black Mesa, yet there was still a need for duplication of equipment for preparation, separation, and pumping facilities. The cost of developing larger equipment would probably offset any economic advantage because it would have very limited application.

The Black Mesa pipeline has a design peak pressure of 1500 psi. The Wyoming to Arkansas line, due to gentle terrain, was estimated by ETSI to have a peak pressure of 900 psi, but their estimates of 3/8" pipe wall thickness for 38" diameter pipe is close to critical design. For a trunk line like Wyoming to Arkansas, the electricity used at the pumping stations would be purchased locally or transmitted from the power plant using the slurry, whichever costs less. A power cost of less than 1.5 cents/Kwh cannot be expected. If the water is to be returned to the mine area, a pipe diameter of 27" will be needed for pairing with the 38" slurry line. There will be additional costs for pumps and power consumption. The ETSI estimate of $250 million for the recycle line only covers the cost of the pipe.

Pumping stations on the Black Mesa pipeline are each equipped with 3 slurry pumps, one of which is standby. Speed can be raised to 4.3 mph when all of them are thrown into operation; peak pressure increases to 1.5 times the design pressure for 3.5 mph flow.

Holding ponds were mentioned but were not tested at the Black Mesa site where local dumping was not deemed impermissible. According to ETSI, for the 25 MMTY shipment, each station is supposed to have a lined holding pond for dumping and a water pump and water reservoir for flushing. For dumping the hold-up in each 100 mile branch, a holding pond of one acre should have a depth of 100 feet. Recovery by dredging has been mentioned by ETSI, but reinjecting into the pipeline is no simple matter and the cost was not provided by ETSI for such standby equipment and, perhaps, cannot be justified within the cost structure. The minimum land area for a pumping station is 4 acres. The ETSI estimate of 3.66 MM ft^3 for a dumping pond at each station is correct, but a holding pond of ten times this capacity might be needed at the delivery point. Flushing water amounting to 27.4 MM gallons will be needed (the ETSI specification of 18.7 MM gallons does not include the volume of coal to be filled by water). Hence, the water reservoir should also be 3.66 MM ft^3 instead of the 2.5 MM ft^3 estimated by ETSI.

The purchase or lease of the right of way for buried lines, except at stations, is similar to oil and gas pipelines. Major towns must be bypassed, river crossings, ravines and gorges may require the use of cable suspended pipe. Cold weather can pose a problem on the exposed portion of the pipe. No existing slurry pipeline passes through a hard freeze area.

For the present comparison, annual fixed charges are estimated on the same basis as that for unit trains. Because almost all the capital costs are front-ended, the line is unusually sensitive to utilization. Coal throughput may be dropped due to conditions at the supply end, the demand end or line problems. For the first two, a significant water flow might still be needed with little reduction in electric usage.

3.3 Operating Costs.

Water is not a major cost item, but there is a problem of availability and the environment. For a 25 MMTY shipment 6.43 billion gallons of water per year are needed (19,700 acre ft.). Costs of $1.00 per 1000 gallons to $2.50 per 1000 gallons may be expected. Estimates by ETSI that water costs of 20 times the cost for agricultural usage of $5-10 per acre ft. means a water cost of only 25 cents to 50 cents per thousand gallons. This is not believed to be realistic,25 cents/1000 gallons in Wyoming is a confiscation level.

Table 3.3 (based on SRI estimates) shows a typical operations and maintenance data sheet similar to that used by Bechtel-ETSI. Their water requirement estimate was in error by a factor of ten times too small and has been corrected. Table 3.4 shows the operation and maintenance labor in man-years. The material, power, water needs and costs are shown in Table 3.5 which has been corrected for a water cost of $1 per thousand gallons and costs escalated to obtain a 1975 base.

3.4 Cost Analysis and Results.

Table 3.6 shows the basic cost and resource items for a specific route and for a given set of operating parameters. Cases include both one way slurry and water return, and designs for both 3.5 mph and 5 mph velocity, and water

Table 3.3

COAL SLURRY PIPELINE
(includes slurry preparation and dewatering)

Prime Input: 25 million tons/year of fine coal (25×10^9 ton-miles/year)

Other Input: $1,267 \times 10^6$/kWh/year electric power, 6.43×10^9 gals water/year

Prime Output: 25 million tons/year of fine coal

Other Output: 6.43×10^9 gals water/year

Days/Year of Normal Operation: 357

Description and Size:

- 25 million tons/year
- 1,000 miles in length
- 38 inches in diameter
- 10 pump stations
- Coal preparation and dewatering facilities.

Table 3.4

MANPOWER REQUIRED FOR OPERATION OF ENERGY FACILITIES

(Average Man-Years per Year)

Coal Slurry Pipeline

(includes slurry preparation and dewatering)

A. NONMANUAL

1. Technical	
a. Engineers:	
Chemical	1
b. Designers and draftsmen	0
c. Supervisors and managers	4
d. Other technical:	
Office employees	2
e. Total technical	7
2. Nontechnical:	
Foreman	52
3. Nonmanual, TOTAL	59

B. MANUAL

1. Craftsmen	
a. Critical skills:	
Pipefitter/welder	8
Electrician	8
Operator, station engineer, pumpman	16
Mechanic helper	16
Mechanic	72
Subtotal	120
b. Other	0
c. Total craftsmen	120
2. Teamsters and laborers	32
3. Manual, TOTAL	152

Table 3.5

MAJOR ITEMS REQUIRED FOR OPERATION AND MAINTENANCE OF ENERGY FACILITIES

(Quantities per Year)

COAL SLURRY PIPELINE

(includes slurry preparation and dewatering)

	Thousands of Dollars
I. MATERIALS	
A. Major Raw Materials, Volume, Energy Content: 25×10^6 tons fine coal/year; 405×10^{12} Btus/year	
B. Other Materials and Supplies	
1. Lumber and Wood Products (20,21):* Lumber	122
2. Paper and Paper Products (24-26)	31
3. Chemicals and Allied Materials (27-32):	
Corrosion retardants	1,378
Other	62
Subtotal	1,440
4. Stone, Clay, and Glass Products (35, 36): Negligible	
5. Nonferrous metals (38): Aluminum, copper products	122
6. Metal Products (39-42): Pipe, valves, and fittings	298
7. Miscellaneous: Negligible	
8. TOTAL	2,013

II. MACHINERY AND EQUIPMENT

1. Nonelectrical machinery (43-50, 52): Negligible
2. Electrical Equipment (53-58): Negligible
3. Transporation Equipment (59-61): Negligible

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*Bureau of Economic Analysis industry category numbers are in parentheses.

Table 3.5 Continued

	Thousands of Dollars
4. Instruments and Controls (62, 63): Negligible	
5. Miscellaneous (64):	
Machinery (pumps, pulverizers, etc.); controls, electrical instruments, communication equipment	2,386
6. TOTAL	2,986

III. UTILITIES

1. Power and Light (68): (1.5¢/kWh)	
Coal preparation 420 x 10^6 kWh (49,020 kW)	6,300
Pipeline movement 847 x 10^6 kWh (98,856 kW)	12,700
2. Fuel (68):	161
3. Water (68): 6.43 x 10^9 gal ($1/1000 gal)	6.43 x 10^6
4. TOTAL	19,161

Table 3.6

BASIC ITEMS - COSTS AND RESOURCES

25 MMTY Slurry Pipeline
One way - 3.5 mph - w/o return water

	Million Dollars			
CAPITAL COSTS:				
A. Gathering	15.5			
Preparation	81.9			
		97.4		(1)
B. Piping = 0.86M		——		(2)
C. Separation Plant & Water Disposal		50.3		(3)
TOTAL Capital Cost (1)+(2)+(3)			——	(4)
ANNUAL COSTS:				
A. Annual fixed charge on debt				
Average rate base	——			(5)
Debt Retirement (30 yrs)				
Rate base:	——			(6)
Federal tax:	——			(7)
State tax:	——			(8)
Depreciation:	——			(9)
Total debt retirement (6)+(7)+(8)+(9)		——		(10)
OPERATING COSTS:				
B. Operating Labor	——			(11)
Administrative	——			(12)
C. Material	——			(13)
D. Power	——			(14)
E. Water	——			(15)
Total Annual Operating Cost (11)+(12)+(13)+(14)+(15)		——		(16)
Total Annual Cost (10)+(16)			——	(17)

Table 3.6 Continued

F. a. \$/ton = (17)/25 (18)

b. ¢/ton-mile = 100 (17)/M (19)

c. ¢/MMBtu = (18) $\frac{10^6}{20(HV)}$ (20)

d. ¢/MMBtu mile = $\frac{(20)}{M}$ (21)

Notes

Item (1) Gathering with 50 ea. 125-ton trucks.
Gathering cost directly proportional to design capacity.

Item (2) In case with water returned to the mine area, 56% additional cost is average (MB). The lower limit is set at 28% (ML).

In case of design for 5 mph, piping of double pressure and double pumping power increases to \$1.30 million per mile.

Item (3) Preparation cost directly proportional to design capacity.

Item (13) For case of design for 5 mph, 25% additional cost.

Item (14) For case of 5 mph, pumping power is doubled, preparation and dewatering power increase by 43%

When water is returned, pumping power is doubled.

Item (15) In case of 5 mph, water required will be 9.26 billion gallons

No water cost when water is returned. 25% make up cost is negligible when acquired in low water cost areas.

costs of both $1 and $2.50, per 1000 gallons. Computational results for various routes and parameters are given in the computer printouts in the Appendix to this section.

Figure 3.1 shows the route specific costs in dollars/ton for each slurry pipeline assuming water costs of $1 per 1000 gallons and $2.50 per 1000 gallons and for both cases of no return and where the water is returned including piping and pumping equipment cost at both the low level of $240,000 per mile (denoted RL in Figures 3.1 and 2.1(a)-(c) in Section 2 for comparison) for the 27" diameter pipe and $480,000/mile as a conservative high value (RH). The figure of $240,000 per mile was close to that suggested by Bechtel and is believed to be the lowest possible cost including pipes and pumps, motors but no new excavation or other route preparation. Depending on current prices of equipment, this figure might buy only the pipe. The figure of $480,000/mile would account for the necessary uphill pumping and a pump designed to handle inky water after separation of the coal from the slurry. When water is returned, the unit cost in cents/ton-mile (Figure 3.1) does not decrease over distance as much as in those cases when water is not returned. Also included in Figure 3.1 are the multipliers for converting the unit costs in tons to unit costs per million Btu (MMBtu). Two multipliers are provided for each source, the 'dry' basis (D) and the 'as mined' basis (M). Because 'as mined' coal includes up to 30 percent moisture by weight, the MMBtu transmitted is close to the 'dry' basis because less water is added to form the slurry. At the delivery end, thd moisture left in the cake after dewatering is at least 25 percent. The moisture causes a loss of approximately 2.5 percent of the heating value based on the weight of dry coal fired.

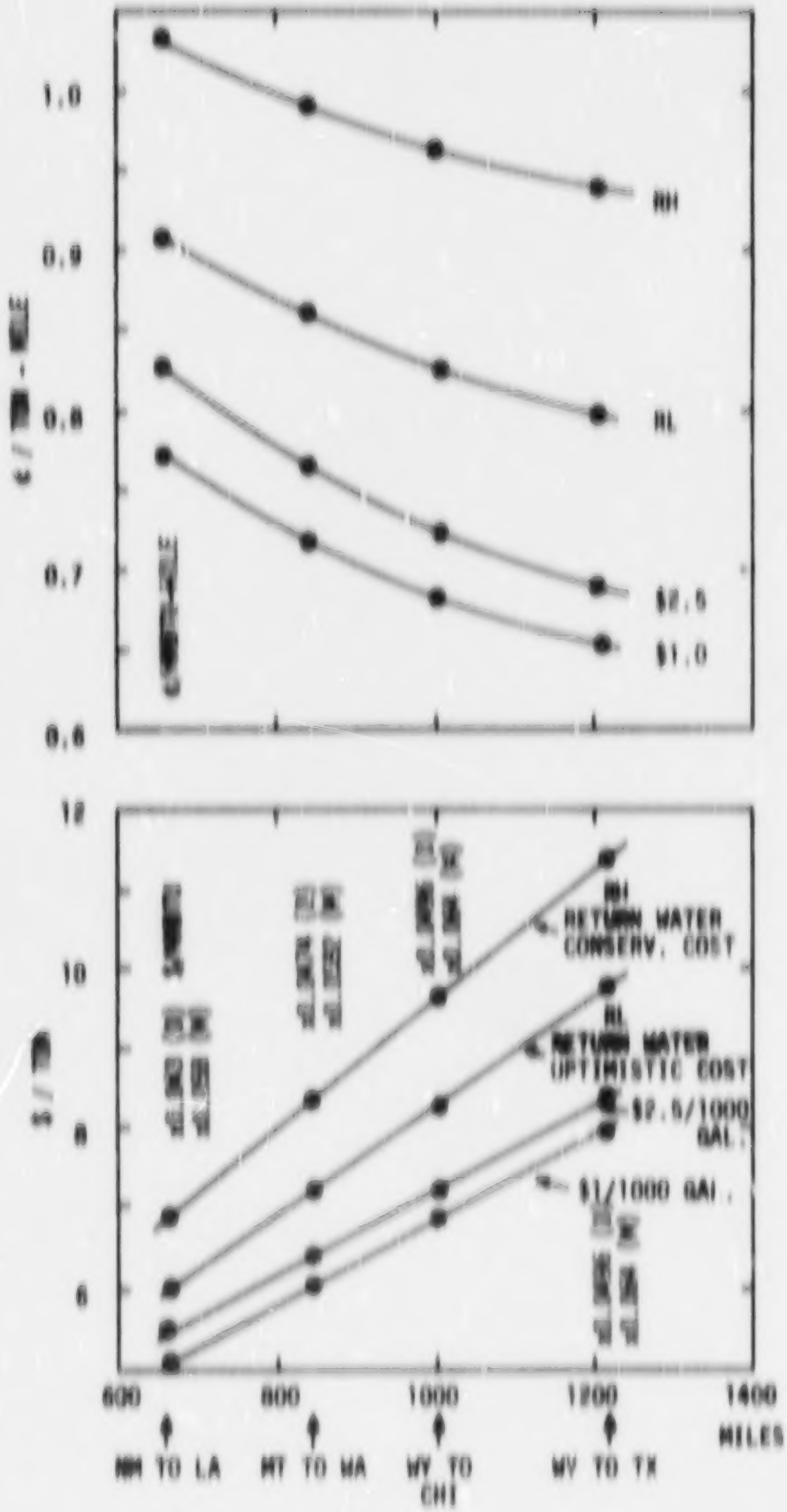

FIGURE 3.1 UNIT COST - SLURRY PIPELINE

Slurry pipelines have a narrow range of operating flexibility even when operating economy is sacrificed. The lower limit of a watery sludge is approximately 65 percent load capacity where the slurry is 30 percent coal. The part load condition is included in the modal comparisons in Section 5.

There is considerable argument concerning water requirements for the slurry pipeline. The often quoted estimate of 15,000 acre feet per year is only for steady state operation of the 25 MMTY pipeline. Flushing of the pipeline with water in 12½ days requires a short-term increase of the pumping rate to 20,000 acre feet/year.

Long distance, large diameter slurry pipelines are not a completely proven technology. The following table contains a list of selected slurry lines but one which includes all of the coal slurry lines; past, present and anticipated. The Consolidation line (Cleveland-Cadiz, Ohio) as late as August 1963, just before shut-down, was referred to as experimental in a joint report by the Consolidation Coal Company and the Cleveland Electric Illuminating Company. More important, the proposed ETSI lines represents an increase by a factor of two in diameter and about 3.5 in length. The remaining operational lines are short distance, small diameter, and low tonnage. Serious problems with such larger, longer, lines are not inconceivable.

Discussions and concern with respect to slurry pipeline shutdown and spillage may be found in: J. Ellis and P. Bacchetti (both of Peabody Coal Co.), "Pipeline Transport of Liquid Coal," Bureau of Mines, IC 8471 (1970). See also E. Wasp, T. Aude, J. Kenny, R. Seiter (all of Bechtel), and R. Jacques (of Black Mesa Pipeline), "Deposition Velocities, Transition Velocities, and Spatial Distribution of Solids in Slurry Pipelines," Hydrotransport 1, First International

Table 3.7

SUMMARY OF SELECTED COMMERCIAL SLURRY PIPE LINES

Slurry material	System or location	Length (miles)	Diameter (inches)	Annual thruput (million tons/year)	Initial operation
Existing					
Coal	Consolidation	108	10	1.3	1957
	Black Mesa	273	18	4.8	1970
Limestone	Calaveras	17	7	1.5	1971
	Rugby	57	10	1.7	1964
	Trinidad	6	8	0.6	1959
	Colombia	17	7	0.4	1944
Copper concentrate	Bougainville	17	6	1.0	1972
	West Irian	69	4	0.3	1972
	KBI Turkey	38	5	1.0	[illegible]
	Pinto Valley	11	4	0.4	1974
Magnetite concentrate	Tasmania	53	9	2.3	1967
	Waipipi (land)	4	8	1.0	1971
	Waipipi (offshore)	1.8	12	1.0	1971
	Pena Colorada	30	8	1.8	1974
Gilsonite	American Gilsonite	72	6	0.4	1957
Tails	Japan	44	12	0.6	1968
Nickel refinery tailings	Western Mining	4.3	4	0.1	1970
In Program					
Coal	Nevada Power Utah/Nevada	180	24	10	
	Energy Transportation Systems, Inc. Wyo./Ark.	1,036	38	25	
Magnetite and Hematite	Sierra Grande	20	8	2.1	
	Brazil	250	20	12	
	Mexico	17	10	1.5	
Planned					
Coal	Houston Natural Gas Colo. to Tex.	750	22	9	
	Gulf Interstate Northwest Pipeline	800	30	16	
Phosphate	Australia	200	18-22	4.0-6.0	
Sulphur/hydrocarbon	Canada	800	12-16	[illegible]	
Magnetite and hematite	Africa	350	18	8.8	
	Brazil	240	20	12.0	
	India	36	20-22	10.0	
	Mexico	17	10	1.5	
	Australia	44	9	0.9	

Conference on the Hydraulic Transport of Solids in Pipes, September 1-4, 1970. Plugging was cited by the Peabody Coal operators during the June 1975 visit of one of our researchers. See also: T. Aude, N. Cowper, T. Thompson and E. Wasp (all of Bechtel), "Slurry Piping Systems: Trends, Design Methods, Guidelines," *Chemical Engineering*, June 28, 1972, for further discussion of the potential problems. More discussion of the plugging problem can be found in E. Wasp and T. Thompson (both of Bechtel), "Slurry Pipelines...energy movers of the future," *Oil and Gas* Journal, December 24, 1973. During our researcher's visit to Black Mesa, Peabody Coal people spoke of having to dig up the plugged line after locating the plug. Part of the line was replaced. In testimony and questioning before the Subcommittee on Energy Research, Development and Demonstration, Committee on Science and Technology, U.S. House of Representatives, January 1976, E. Wasp (Bechtel/ETSI) admitted having to drill out the plug.

The seriousness of the plugging of a slurry pipeline may be visualized as follows: when a plug is noted between two stations along a 1000 mile line, with station spacing of 100 miles, each station will begin to dump the slurry into a holding pond of one acre by 100 feet deep. It will also begin to introduce water from a flushing pond or other local water source by pumping water into the line. For each branch, complete flushing takes 30 hours. In the meantime, the plug is located within the 100 mile sector followed by digging and plug removal. This process is expected to take at least a week.

Subsequently, the slurry is reintroduced into the pipeline from the supply point, while the flushing water is returned to the ponds at each of the stations. The slurry

dumped at each station will not be reintroduced unless special injection equipment is provided which, considering the cost, is unlikely if 99 percent operating reliability is practiced. After this new start, the coal supply will reach the delivery point 12½ days later thus giving a total stoppage time of almost 3 weeks. The water from the last branch of the pipe, amounting to 19 million gallons, has to be disposed of. This water is too dirty to simply dump and contains too little coal to warrant dewatering and subsequent use of the coal. Storage of slurry or "cake" against such a contingency is costly and environmentally problematic; a slurry holding pond of 10 acres by 200 feet will be needed. Unless treated, the holding ponds themselves may constitute health hazards. If the ponds are not lined, the water percolates into the soil and/or evaporates and the now dried coal may wind drift. If the ponds are lined a non-environmentally hazardous method must be found for disposal.
If slurry line shutdown involves the purchase of power at the receiving end, such power is more costly than "own" produced power. If the purchase involves the use of the network, a "wheeling charge" (service charge) of about 10 percent of the cost is added by each utility through which the power is bumped. Finally, while the water flow rate during operation amounts to 15,000 acre-feet/year, the flushing rate, throughout its duration, amounts to about 28,000 acre-feet/year. Far more serious than the additional water usage is the environmental problem of the disposal of the flushing water; a very dilute unuseable suspension of coal in a large volume of water. A line break has all of the problems suggested above, but the break is unlikely to be considerately near a dump pond. No provision has been reported for breakage. Leaks and breaks in oil and gas lines are familiar to all of us.

The return of the water is desirable where the use of the water for the slurry poses a serious problem to the local economy and/or the environment. Even when water is available to agriculture at 3 cents/1000 gallons ($10 per acre-foot), the willingness of the slurry pipeline operators to pay $2.50/1000 gallons may not be a sufficient reason to deprive the farm sector of 6 billion gallons of water per year. A case in which water has to be returned to the mine area occurs when the slurry is to be dewatered for export, because, without a power plant sited at the delivery end, there is no means for evaporating the ink after dewatering.

The undesirability of operating a pipeline designed for 3.5 mph at 5 mph is seen in the doubling of pumping power and a pipeline pressure at 143 percent of design capacity. Since each pumping station on the Black Mesa pipeline is equipped with 3 pumps with one as a spare, if this practice is applied, operating at 122 percent capacity is feasible provided the line can take a 50 percent increase in operating pressure. In this case the unit transportation cost will be reduced by 18 percent. Similarly, operating at the minimum flow velocity of 3 mph gives a transfer capacity of 86 percent for the same slurry at 75 percent of the power need. In this case, unit costs are increased by 15 percent.

One option is to design a pipeline for 5 mph thus giving the flexibility of a reduced load at 3.5 mph or 3 mph. For purposes of comparison, a case was calculated (Table 3.8), showing changes in costs for such a pipeline operating at 3.5 mph. Note that while a pipeline designed for 5 mph may have a unit cost of only 5 percent higher than a 3.5 mph line, when the former is operated at 3.5 mph the unit cost will be 40 percent higher, for a 40 percent capacity

Table 3.8

CHANGES IN COSTS PER 1000-MILE PIPELINE DESIGNED FOR
5 MPH FLOW AT 5 MPH AND 3.5 MPH AS COMPARED TO
ONE DESIGNED FOR 3.5 MPH
(in million dollars)

Design	5 mph Line		3.5 mph Line
Operating Flow	5 mph	3.5 mph	3.5 mph
Operating Capacity, MMTY	36	25	25
Capital Costs:			
Gathering	22.3	22.3	15.5
Preparation	117.9	117.9	81.9
Piping & Pumping	1300	1300	860
Separation	72.4	72.4	50.3
Total	1512.6	1512.6	1007.7
Annual Costs:			
Fixed Charges			
Rate Base	93.8	93.8	62.5
Federal Tax	26.1	26.1	17.5
State Tax	30.1	30.1	20.1
Depreciation	50.4	50.4	33.6
Total	200.8	200.8	133.7
Operating Costs			
Labor	6.9	6.9	6.9
Material	6.25	5	5
Power	34.1	19	19
Water ($1/1000 gal)	9.3	6.4	6.4
Total Annual Cost	258.6	239.3	171.0
Unit Cost:			
$/ton	7.18	9.57	6.85
¢/ton-mile	.72	.96	.69
¢/MMBtu	36	48	33.9
¢/MMBtu/mile	.036	.048	.034

range. Note also that a unit train system has a unit cost range of only 15 percent for a capacity range of 60 percent. The proposed slurry pipeline for shipping coal from New Mexico and Colorado to Houston with deliveries along the way is an example of a pipeline with gathering and branching. The costs cited in their proposal show general agreement with our estimates. Note, however, that successful operation calls for a nearly steady flow; delivery must be maintained even if a power plant along the way is shut down.

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APPENDIX SECTION 3

COSTS AND RESOURCES FOR SLURRY PIPELINES

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CAPITAL COSTS		ANNUAL COSTS				UNIT COSTS	
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CAPITAL COSTS		ANNUAL COSTS				UNIT COSTS	
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CAPITAL COSTS		ANNUAL COSTS				UNIT COSTS	
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		TOTAL ANNUAL COST	[illegible]				

COSTS AND RESOURCES FOR SLURRY PIPELINE

MILLION DOLLARS - 25 MMTY - [illegible]

ROUTE - GILLETTE - CHICAGO - [illegible] MILES

COST OF WATER [illegible]

CAPITAL COSTS		ANNUAL COSTS				UNIT COSTS	
		ANNUAL FIXED CHARGE ON INVESTMENT		OPERATING COSTS			
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PIPING	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SEPARATION PLANT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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CALCULATION FOR RETURN WATER

CAPITAL COSTS		ANNUAL COSTS				UNIT COSTS	
		ANNUAL FIXED CHARGE ON INVESTMENT		OPERATING COSTS			
PREPARATION	[illegible]	[illegible]	[illegible]	OPERATING LABOR	[illegible]	[illegible]	[illegible]
PIPING	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SEPARATION PLANT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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		TOTAL ANNUAL COST	[illegible]				

COSTS AND RESOURCES FOR SLURRY PIPELINE

MILLION DOLLARS - 25 MMTY - [illegible]

ROUTE - GILLETTE - CHICAGO - [illegible] MILES

COST OF WATER [illegible]

CAPITAL COSTS		ANNUAL COSTS				UNIT COSTS	
		ANNUAL FIXED CHARGE ON INVESTMENT		OPERATING COSTS			
PREPARATION	[illegible]	[illegible]	[illegible]	OPERATING LABOR	[illegible]	[illegible]	[illegible]
PIPING	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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		TOTAL ANNUAL COST	[illegible]				

COSTS AND RESOURCES FOR SLURRY PIPELINE

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[illegible] • [illegible] • [illegible] • [illegible] MILES

COST OF WATER [illegible]

CAPITAL COSTS		ANNUAL COSTS				UNIT COSTS	
		ANNUAL FIXED CHARGE ON DEBT		OPERATING COSTS			
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SEPARATION PLANT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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CALCULATION FOR RETURN WATER

CAPITAL COSTS		ANNUAL COSTS				UNIT COSTS	
		ANNUAL FIXED CHARGE ON DEBT		OPERATING COSTS			
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		TOTAL ANNUAL COST	[illegible]				

COSTS AND RESOURCES FOR SLURRY PIPELINE

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COST OF WATER [illegible]

CAPITAL COSTS		ANNUAL COSTS				UNIT COSTS	
		ANNUAL FIXED CHARGE ON DEBT		OPERATING COSTS			
PREPARATION	[illegible]	[illegible]	[illegible]	OPERATING LABOR	[illegible]	[illegible]	[illegible]
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SEPARATION PLANT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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COSTS AND RESOURCES FOR SLURRY PIPELINE

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COSTS AND RESOURCES FOR SLURRY PIPELINE

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SECTION IV

EXTRA HIGH VOLTAGE TRANSMISSION

4.1 Introduction.

Coal, as electrical energy in large blocks, can be transported from mine mouth generating plants to distant load centers. Particularly in more densely populated areas, if environmental issues can be surmounted, this form of transport may be the least costly.

While for economic reasons, the emphasis here is on DC rather than AC transmission, both alternatives are compared. Five routes are investigated. These are to Los Angeles from Kaiprowits, Utah (1-6) and Farmington, New Mexico (2-6); and to Chicago from Beulah, North Dakota (3-7), from Gillette, Wyoming (4-7), and from Colstrip, Montana (5-7). A general cost analysis is also presented.

4.2 Extra High Voltage Transmission - AC-DC Comparison

In its earlier development, power demand was primarily from isolated places or individual industrial plants, and load was fed locally. Therefore, voltages were low, distances were short, and direct current was exclusively transmitted. The development of AC transformers offered advantages in the use of high voltage to compensate for distance. Therefore, AC usage superseded DC. AC transmission is again being challenged because transmission voltages have reached levels which are so high that reactive compensation is too costly and line losses are very high. Economics is dictating a switch back to DC transmission. Currently, there are eleven major HVDC lines in operation (see following table) with more in the final planning stage.

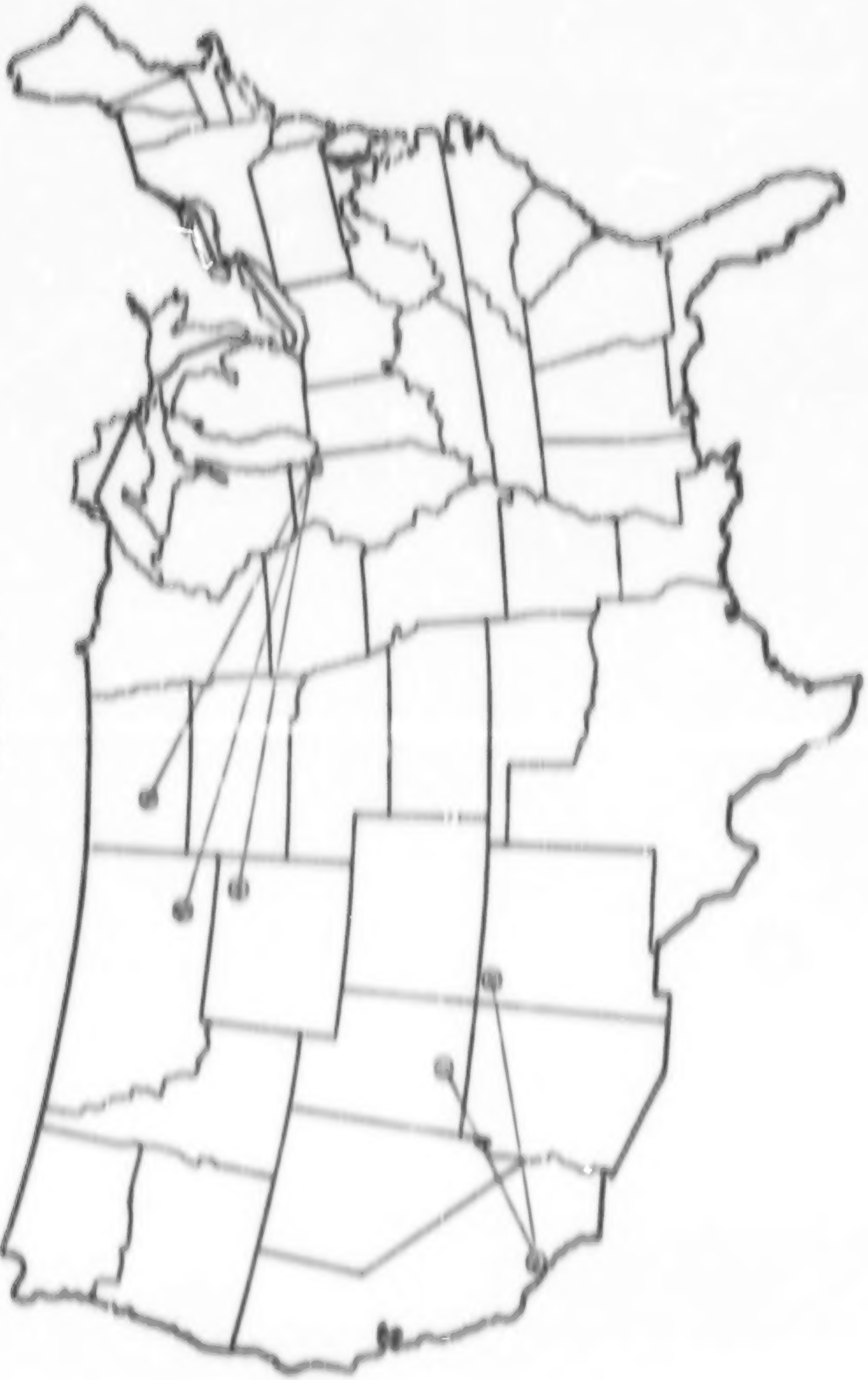

Figure 4.1

Table 4.1

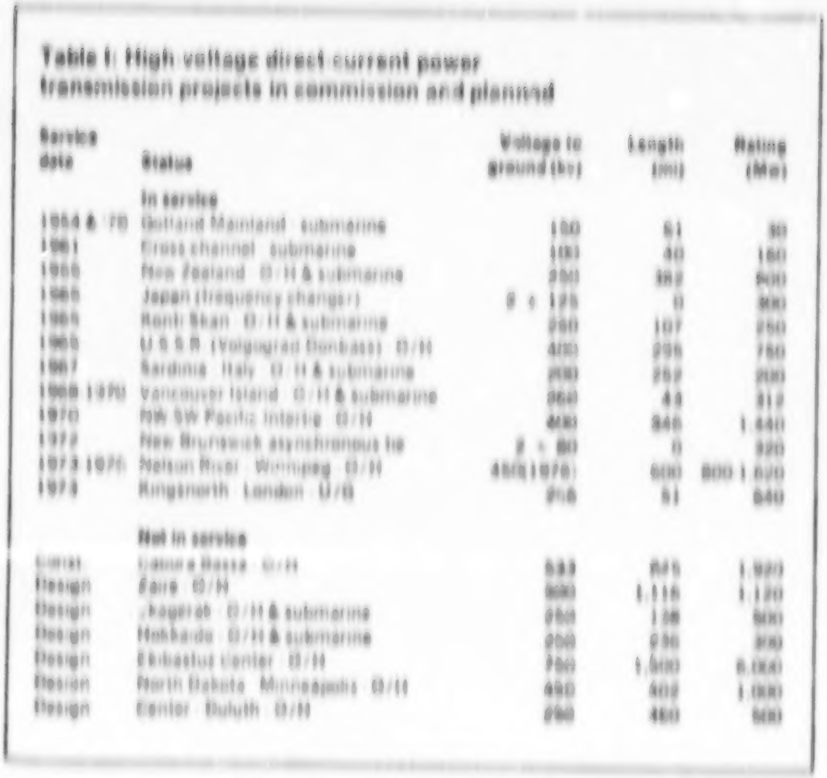

Table I: High voltage direct current power transmission projects in commission and planned

Service date	Status	Voltage to ground (kv)	Length (mi)	Rating (Mw)
	In service			
1954 & '70	Gotland Mainland · submarine	150	61	30
1961	Cross channel · submarine	100	40	160
1965	New Zealand · O/H & submarine	250	382	600
1965	Japan (frequency changer)	2 × 125	0	300
1965	Konti Skan · O/H & submarine	250	107	250
1965	U.S.S.R. (Volgograd Donbass) · O/H	400	295	750
1967	Sardinia · Italy · O/H & submarine	200	252	200
1968 1970	Vancouver Island · O/H & submarine	260	43	312
1970	NW SW Pacific Intertie · O/H	400	846	1,440
1972	New Brunswick asynchronous tie	2 × 80	0	320
1973 1975	Nelson River · Winnipeg · O/H	450(1975)	600	800 1,620
1975	Kingsnorth · London · U/G	266	51	640
	Not in service			
Const.	Cabora Bassa · O/H	533	825	1,920
Design	Zaire · O/H	500	1,116	1,120
Design	Skagerak · O/H & submarine	250	136	500
Design	Hokkaido · O/H & submarine	250	236	300
Design	Ekibastuz Center · O/H	750	1,500	6,000
Design	North Dakota · Minneapolis · O/H	400	402	1,000
Design	Center · Duluth · O/H	250	460	500

Source: Electric World, p. 44, July 1, 1974.

Theoretically, HVDC systems have some advantages over equivalent AC counterparts. Most important, they have a much higher power density within a given right of way than an AC system. This provides economic and environmental advantages. Furthermore, in transmitting the same amount of power over the same size conductor at the same peak load gradient for the same distance line losses are smaller with direct current. AC line losses are about 33 percent greater than those for DC. The following calculation represents the basis of comparison between AC and DC power transmission:

Line Loss ratio for equal power transmitted.

Assume:

3-Phase AC
Bipolar DC
Same conductor resistance per mile, $R_{L_{AC}} = R_{L_{DC}}$
Same crest voltage stress on insulation and clearance.

E = Voltage; I = Current; P = Power.
rms = root mean square.

where,

$$P_{AC} = \sqrt{3}\, E_{rms}\, I_{rms}$$

$$P_{DC} = E_{DC}\, I_{DC}$$

$$E_{rms} = \frac{\sqrt{3}}{\sqrt{2}}\, E_{n\ crest}\ (AC)$$

$$E_{DC} = 2E_{n\ crest}\ (DC)$$

Therefore,

$$P_{AC} = P_{DC}$$

$$\sqrt{3}\ E_{rms}\ I_{rms} = E_{DC}\ I_{DC}$$

$$\sqrt{3}\ \frac{\sqrt{3}}{\sqrt{2}}\ E_{n\ crest}\ I_{rms} = 2E_{n\ crest}\ I_{DC}$$

$$I_{rms} = \frac{2\sqrt{2}}{3}\ I_{DC}$$

Line Loss:

$$LL_{AC} = 3I^2_{rms}\ R_L = 3\left(\frac{2\sqrt{2}}{3}\ I_{DC}\right)^2\ R_L$$

$$LL_{DC} = \text{Line Loss} = 2I_{DC}^2\ R_L$$

$$\frac{LL_{AC}}{LL_{DC}} = \frac{3\left(\frac{2\sqrt{2}}{3}\right)^2}{2} = \frac{4}{3}$$

Therefore, neglecting the AC skin effect, AC line losses are 33 percent greater than DC losses for the same conductor voltage stresses and the same power transmitted.

Among the advantages of DC power generation are the following:

1. Greater power per conductor.
2. Lighter and simpler line and tower construction, reducing cost and secondary impacts.
3. A ground return can be used. Hence, each conductor can be operated as an independent circuit.

4. No charging current.
5. No skin effect.
6. The cables can be worked at a higher voltage gradient.
7. The line power factor is always unity; the line does not require reactive compensation.
8. There is less corona loss and radio interference than for AC transmission, especially in bad weather, for given conductor diameter and rms voltage.
9. Synchronous operation is not required. Therefore, distance is not limited by stability.
10. A DC system may interconnect with AC systems of different frequencies.
11. There is low short circuit current on a DC line. It does not contribute to short circuit on an AC line.
12. Tie-line power is easily controlled.

The chief drawback to the use of DC for electric power transmission is the high cost of HVDC terminal equipment. In the early 1960's cost estimates for terminals were about $25/kw [12][17]. Even though the development of solid-state valves has helped to hold down costs, this seems to have had little effect on the overall cost reduction of these major items.

4.3 The EHV Cost Model.

The costing, but not the technical, analysis in this section must be considered more tentative than that developed for unit trains and slurry pipelines. This situation may be remedied in the next 3-4 months with the publication by EPRI, of a commissioned study by Commonwealth Associates which will include an analysis of 765 kv overhead line.

Comparisons between the total costs of DC transmission with those of conventional AC transmission are difficult because of the lack of a proper definition of equivalence of systems and because of the diversity of outdated published cost information for both systems. The range of results of various studies made in the past vary widely [8],[9],[13], and introduce some doubt as to the accuracy of the conclusions which may be drawn from them. Unless account is taken of the continual changes which are taking place in equipment design, manufacturing techniques, market prices and the expected utilization of the line over a long period of time, it is difficult to utilize studies made at different times.

Given current operating and equipment limitations for DC facilities, comparisons between AC and DC transmission are based on point to point lines, with complete terminal facilities at each end, for a range of loads and distances. The systems are non-comparable if either one has more intermediate line terminals or line taps than the other.

Estimated total costs for each system includes fixed charges on investment, operating and maintenance costs, and both line and terminal equipment losses. These data are used to determine the breakeven distances at which DC costs equal AC costs for any given value of power delivered to the receiving terminal of the transmission system. A cost model for extra-high voltage transmission is formulated to evaluate the economics of an EHV transmission line for source to load long distance electrical energy transfer. It it also used to formulate and demonstrate the economic comparison between EHV-AC and EHV-DC transmission.

4.4 Results.

The cost model is self-described by the data presented in Tables 4.2 - 4.5. Pertinent assumptions are given in Tables 4.6 - 4.7. Route specific data are shown in Table 4.8. Figure 4.2 indicates the breakeven point for AC and DC transmission for the relevant voltage.

Given the facilities description, it is estimated that for a double circuit HVDC transmission line, the weight of self-supporting steel towers ranges from 61-112 tons/mile. Guyed steel or aluminum towers would weigh 45-67 tons/mile. In general, the AC towers use 1.67 times the material used in DC towers.

For AC transmission, conductor requirements are estimated from 62-89 tons/mile of steel reinforced aluminum wire. DC transmission requires about 54 tons/mile.

Estimated Unit Cost of EHV Transmission of 3000 Mw (1975$)

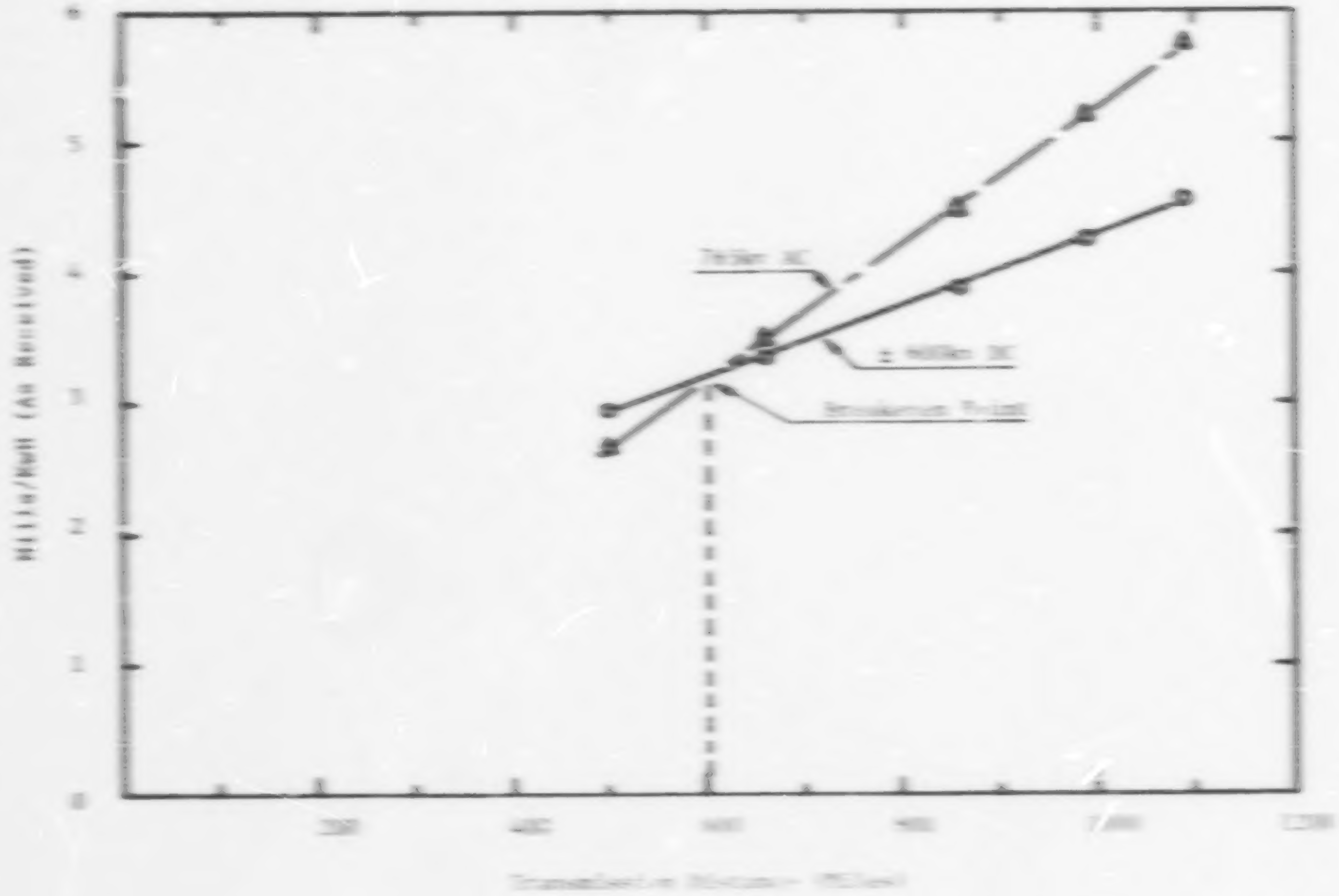

Table 4.3

ESTIMATED INVESTMENT OF 1000 MILE EHV TRANSMISSION OF 3000 MW

(1975 dollars)

765 kv AC Transmission

SENDING SUBSTATION:		
Building & Site Development		800,000
Structures		2,027,500
765 kv Terminals with Breakers		13,246,000
Generator Step-up Transformer 22/765 kv		14,261,400
Transformer Connections with Breakers		5,745,000
Total: Sending Substation		36,079,900
RECEIVING SUBSTATION:		
Building & Site Development		800,000
Structures		2,027,500
765 kv Terminals with Breakers		13,246,000
345 kv Terminals with Breakers		2,365,500
Auto-Transformers, 3-10-765/345 kv		17,551,200
Transformer Connections with Breakers		5,745,000
Total: Receiving Substation		41,735,200
COMPENSATION FACILITIES:		
Series Capacitors ($14.0/kvar)		59,500,000
Shunt Reactors ($24.2-$13.0/kvar)	102,850,000 -	55,250,000
Shunt Capacitors ($11.4-$9.9/kvar)	16,530,000 -	14,355,000
Total: Compensation Facilities	178,880,000 -	129,105,000
TRANSMISSION FACILITIES:		
Line & Tower (Double Circuit)	(Self-Support)	433,390,000
	(Guyed)	353,690,000
Rights of Way (Including Clearing) (225 Ft RoW, $1500/acre)		40,500,000
Total:	473,890,000 -	394,190,000

±600 kv DC Transmission

SENDING SUBSTATION:	123,000,000
RECEIVING SUBSTATION	118,712,000
TRANSMISSION FACILITIES	236,000,000
RIGHTS OF WAY (Including Clearing) (175 Ft RoW, $1500/acre)	31,500,000

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Table 4.4

COST ANALYSIS OF 765 KV[†] EHV AC TRANSMISSION SYSTEM

(1975 dollars)

(3000 MW, 1000 Mile)

I. CAPITAL INVESTMENTS:		
A. Sending Substation	35,651,600	
B. Receiving Substation	41,306,900	
C. Compensation		
C1. Series Capacitors @ $14.0/kvar	59,500,000	
C2. Shunt Reactors @ $18.6/kvar	75,050,000	
C3. Shunt Capacitors @ $10.65/kvar	15,442,500	
D. Transmission Line Facilities @ $353,690/mile	353,690,000	
E. Right of Way @ $1500/acre	40,500,000	
Total Capital Costs:		625,141,000
II. ANNUAL FIXED COSTS:[*]		
A. Sending Substation @ 13.9% of IA	4,956,000	
B. Receiving Substation @ 13.9% of IB	5,743,000	
C. Compensation @ 13.9% of IC	21,405,000	
D. Transmission Facilities @ 13.5% of ID	47,748,000	
Total Annual Fixed Costs:		79,851,600
III. ANNUAL OPERATING COSTS:[**]		
A. Sending Substation @ 2.34% of IA	834,000	
B. Receiving Substation @ 2.60% of IB	1,074,000	
C. Compensation @ 1.3% of IC	2,002,000	
D. Transmission Facilities @ 1.3% of ID	4,598,000	
E. Electrical Energy Losses:	32,850,000	
E1. Energy Losses @ 1¢/kwh		
Total Annual Operating Costs:		41,358,000
IV. ANNUAL COSTS: (II + III)		121,209,000
V. UNIT COSTS:		
A. Mills/ton-mile of equivalent coal		10.48
B. Mills/kw-hr received power		5.271
C. Investment $/annual MWH received power		238.15

[†] Double circuit is used.

[*] Based on FPC P-38 Annual fixed charge rate.

[**] Includes administrative and general expenses @ 3.0% of their operating costs.

Table 4.5

COST ANALYSIS OF ±600 KV EHV-DC TRANSMISSION SYSTEM
(1975 dollars)
(3000 MW, 1000 Mile)

I. CAPITAL INVESTMENTS:		
A. Sending Substation @ $41/kw	123,000,000	
B. Receiving Substation @ $44/kw	118,712,000	
C. Transmission Facilities @ $236,000/mile	236,000,000	
D. Right of Way @ $1500/acre	31,500,000	
Total Capital Costs:		509,212,000
II. ANNUAL FIXED COSTS:		
A. Sending Substation @ 13.9% of IA	17,097,000	
B. Receiving Substation @ 13.9% of IB	16,501,000	
C. Transmission Facilities @ 13.5% of IC	31,860,000	
Total Annual Fixed Costs:		65,458,000
III. ANNUAL OPERATING COSTS:		
A. Sending Substation @ 2.34% of IA	2,878,200	
B. Receiving Substation @ 2.60% of IB	3,086,500	
C. Transmission Facilities @ 1.30% of IC	3,068,000	
D. Electrical Energy Losses: D1. Energy Losses @ 1¢/kwh	26,542,800	
Total Annual Operating Costs:		35,575,500
IV. TOTAL ANNUAL COSTS:		101,033,500
V. UNIT COSTS:		
A. Mills/ton-mile of equivalent coal		0.503
B. Mills/kw-hr received power		4.28
C. Investment $/annual MWH received power		108.8

Table 4.6

ESTIMATING ASSUMPTIONS

A. Assumptions applying to both AC and DC transmission calculations:

1. From source to load point-to-point transmission is assumed.

2. Investment costs for transmission lines and substation facilities are taken from our estimation of a typical unit.

3. For the purpose of estimation and comparison, annual fixed charges, as a percentage of investments are assumed to be 13.9 percent for substations and facilities, and 13.5 percent for steel tower transmission lines (from data released by FPC).

4. Annual operating and maintenance costs as a percentage of total investment, are assumed to be 1.8 percent for sending substation, 2 percent for receiving stations, and 1 percent for transmission lines and compensatory facilities.

5. The cost of energy losses is assumed to be 1¢/kwh.

6. Power loss is calculated to cost $150 per kilowatt and annual fixed charge of 13.9 percent.

7. Annual load factor of 100 percent is assumed.

B. Assumptions applying only to AC transmission calculations:

1. Series compensation is used to raise the power loading of the AC line for long distance electric transmission. The amount of series compensation, where needed, is estimated [11] and is considered a good approximation of optimum economic application.

Table 4.6 Continued

4. The sending-end voltage is 105 percent of rated voltage.

5. Shunt capacitors are installed on the transformer tertiary at the receiving terminals as required to provide 100 percent voltage at the EHV bus with a load of unity power factor at the low voltage bus.

6. The high values of charging current met with in 765 kv lines necessitate the use of shunt reactors. These act as a very effective means of reducing excessive reactive current and energy losses at low load.

7. All reactors are connected directly to the transmission line and are assumed to be in service under all conditions, except when disconnected for maintenance.

8. All auto-transformers are assumed to be stepped down to 345 kv at the receiving end.

9. AC line loss calculations are estimated from "Best Case" formula [10].

10. Only transformer losses which constitute the major part of terminal equipment losses are accounted for and are assumed to be 0.9 percent of the power rating.

Table 4.7

EHV SOURCE TO LOAD TRANSMISSION SYSTEM SPECIFICATIONS

	765 kv AC	±600 kv DC
Transmission Capacity, MW	3000	3000
Transmission Distance, Miles	1000	1000
Heating value of coal, Btu/lb	6500	6500
Plant factor, %	70	70
Heat rate, Btu/kWh	9500	9500
Coal consumption rate, ton/year	13,217,300	13,217,300
Conversion efficiency, %	35.9	35.9
Line losses, MW	347.2	260.4
Substation equipment losses, MW	27	42.0
Delivered Capacity, MW	2625.8	2697.6
Transmission efficiency, %	87.5	89.9

Table 4.8

ROUTE SPECIFIC COSTS**

ROUTES	(1) – (5)		(2) – (6)		(3) – (7)		(4) – (7)		(5) – (7)	
Estimated Transmission Length (mi)	495		650		858		990		1389	
Heating Value of Coal (Btu/lb) Coal Consumption (MTons/Year)	10900 10.4		8600 13.1		7500 15.0		11700 9.6		6700 12.9	
Transmission Voltage (kv)	±600 DC	765 AC	±600 DC	765 AC	±600 DC	765 AC	±600 DC	765 AC	±600 DC	765 AC
Transmission Loading (MW)	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
Delivered Power (MW)	2829	2802	2787	2745	2736	2675	2700	2628	2676	2595
Transmission Efficiency (%)	94.3	93.4	92.9	91.5	91.2	89.2	90.0	87.6	89.2	86.5
CAPITAL COSTS:										
Sending Substation	123.0	35.65	123.0	35.65	123.0	35.65	123.0	35.65	123.0	35.65
Transmission Facilities	126.8	175.1	155.8	232.6	202.5	303.5	233.6	350.1	257.0	385.2
Receiving Substation	124.5	42.38	122.6	42.38	120.3	42.38	119.0	42.38	117.7	42.38
Line Compensation	0	63.6	0	93.1	0	128.6	0	152.2	0	170.0
Right of Way Cost*	15.6	20.05	20.8	26.73	27.0	34.75	32.2	40.1	34.3	44.1
Total Capital Costs	379.5	335.7	422.2	430.3	472.9	543.0	506.7	629.4	532	676.2
ANNUAL FIXED COSTS:										
Sending Substation*	17.1	4.96	17.1	4.96	17.1	4.96	17.1	4.96	17.1	4.96
Transmission Facilities*	15.77	23.64	22.03	31.51	27.34	40.97	31.54	47.27	34.70	52.0
Receiving Substation*	17.3	5.74	17.0	5.74	16.73	5.74	16.52	5.74	17.36	5.74
Line Compensation	0	8.84	0	12.95	0	17.87	0	21.16	0	23.62
Total Annual Fixed Costs	50.17	43.17	55.17	55.16	61.16	69.54	65.16	79.12	68.25	86.31

Table 4.9 Continued

ROUTES	(1) - (6)		(2) - (6)		(3) - (7)		(4) - (7)		(5) - (7)	
ANNUAL OPERATION COSTS:+										
Sending Substation	2.88	0.83	2.88	0.83	2.88	0.83	2.88	0.83	2.88	0.83
Transmission Facilities	1.57	2.28	2.02	3.03	2.63	3.95	3.04	4.55	3.34	5.00
Receiving Substation	3.24	1.07	3.19	1.07	3.13	1.07	3.09	1.07	3.06	1.07
Line Compensation	-0-	0.83	-0-	1.21	-0-	1.67	-0-	1.98	-0-	2.21
Electrical Energy Losses	14.93	17.35	18.66	22.34	23.13	28.47	26.29	32.59	29.96	35.48
Total Annual Operation Costs	22.62	22.36	26.75	28.48	31.77	35.99	35.29	41.02	39.24	44.59
TOTAL ANNUAL COST:	72.75	65.51	81.92	83.64	92.93	105.53	100.45	120.14	107.39	130.9
UNIT COSTS:										
Mills/Ton-Mile (equivalent coal)	15.0	13.63	10.2	10.57	7.92	9.19	11.74	14.43	8.57	10.7
Mills/kw (as received)	2.94	2.67	3.36	3.48	3.88	4.50	4.25	5.22	4.58	5.76
Invest. $/kw (as received)	134.3	129.8	223.3	156.8	170.8	203.3	187.7	235.7	198.8	262.6
Land Requirement for Transmission Lines (Acres)	10395	12365	13860	17820	18018	23166	20790	26730	22870	29403

+ Including right of way, $1500/acre.

† Includes administrative and general expenses @ 30% of operating costs.

* Based on FPC P-38 Annual Fixed Charges Rate.

** Consistent with "as mined" BF data in Table 3.1.

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APPENDIX A TO SECTION IV

EHV TRANSMISSION SAFETY AND ENVIRONMENT

APPENDIX A TO SECTION IV

SAFETY AND ENVIRONMENT

Concern over extra high voltage transmission lines centers around line leakage, physiological effects due to proximity, noise, odor, radio and television and other communication interference and aesthetics. Significant material has been developed under EPRI auspices [19] concerning corona phenomena on AC transmission lines, radio and television interference, corona loss, and the electrostatic effects of overhead transmission lines and stations. Studies are currently underway in EPA and EPRI among others. There appear to be few additional tangible results.

The following excerpts are reproduced from Federal Power Commission sources [17][16B].

This material has been omitted. See sections 3.1 through 3.4 of reference [17] and sections 2.5, 6.3.11, and 6.3.12 of reference [16b].

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APPENDIX B TO SECTION IV

EHV TRANSMISSION COMPARATIVE DATA

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APPENDIX B TO SECTION IV

COMPARATIVE DATA:
765 KV AC AND ±600 DC

Data obtained from the Missouri Public Service Commission, based on an analysis by Commonwealth Associates, Inc., included the following points of reference.

(1) Total per mile costs for 765 kv AC transmission are estimated at $300,000.

(2) For equal mileage, line losses for a 765 kv AC line are 10 percent of those for a 345 kv AC line.

(3) For "equal" lines, the cost per mile for DC transmission is approximately two-thirds that for AC.

(4) DC transmission can ship more power per unit right of way than AC. A further advantage is that it can be operated at half capacity during some equipment troubles.

(5) Present estimates of terminal costs are about $40/kw for a DC line.

(6) There are no currently available breakers to sectionalize a DC line.

(7) For the 456 mile HVDC line currently being constructed between Center, North Dakota and Duluth, Minnesota, the connecting DC transmission line is estimated at $25 million, the two terminals will cost over $45 million.

Data supplied by the Bonneville Power Administration included the following:

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(1) The cost of d-c converter stations depends on a number of factors, the major ones being the capacity, the nature of the a-c systems to which they are connected, availability requirements, d-c voltage levels and location.

(2) Generally, the cost of the terminal in terms of dollars per KW goes down with higher capacity. Excluding the cost of land for the terminal, cost of a-c system additions, spares and utility overhead, installed cost of HVDC terminals of 1500-3000-MW capacity would be in the range of $37 to $32 per kW per terminal.

(3) Modern HVDC terminals are based on solid-state converter technology and are typically made up of 12-pulse converters. In general, the minimum cost terminal would have only one 12-pulse converter group per pole. However, depending on the system reliability requirements, it might be desired to have at least two 12-pulse converter groups per pole. In this case, the cost of the terminal will go up by about ten percent of the figures quoted above.

(4) The cost of integrating the d-c terminal with the power system depends on the existing a-c systems. Apart from the cost of facilities needed to connect the d-c terminals to the a-c system, the voltage level of the a-c supply to the converters can influence the cost. The figures quoted above are typical for 230- or 345-kV systems. Higher voltage, 500-kV or 760kV, a-c supply would increase the cost.

(5) The cost of the d-c line varies with voltage level, conductor size and terrain.

(6) For typical ± 400-kV d-c line, some of our recent preliminary cost estimates indicated a price range of $115,000 to $130,000 per mile depending on conductor size. These figures do not include cost of land and administrative

overhead. Smooth terrain was assumed. Similar cost estimates for ± 600-kV line ranged from $165,000 to $200,000 per mile depending on conductor size.

(7) A typical ± 400-kV line could be constructed of two Thrasher (2312 kcmil) conductors per pole. Cost of this configuration based on the assumptions given above would be about $127,000 per mile. These would be single-circuit steel structures requiring approximately 31 tons of steel per mile. A similar typical ± 600-kV line could use 3 Chukar (1780 kcmil) conductors per pole and would require about 44 tons of steel per mile. The cost of this line excluding land and overhead would be about $180,000. These designs are based on grillage footings whose steel amounts are included in the above figures. As to conductor weights, a Thrasher condcutor weighs 2.53 lb/ft. and Chukar 2.076 lb/ft.

(8) Depending on the assumptions regarding average span, terrain and wind loading, the right-of-way for the ± 400-kV line would be in the range of 110 ft.-140 ft. and for the ± 600-kV line in the range of 130 ft.-160 ft.

In its draft final Report to ERDA, *Clean Coal Energy: Source-to-Use Economics*, Vol. 1, "Model, Data, and Results," January 1976, the Bechtel Corporation has presented some generalized data which are reproduced below.

This material has been omitted. See pages 2-50, 2-51, and 2-52 of the reference cited above.

SECTION V

CONCLUSIONS

5.1 General.

Western coal is not necessarily low sulfur coal. In the designated supply regions there is often a considerable difference between the sulfur content of the coal as mined and the sulfur content of the coal on the Btu basis which must be used to meet EPA regulations. The standardized basis selected for comparison is 22.6 MMBtu/ton, the 1970 utility average. A comparison for each of the supply locations follows:

Source	Sulfur Content As Mined (%)	Btu Adjusted (%)
Kaiparowits	0.52	0.55
Farmington	0.70	0.92
Gillette	0.3 - 0.8	0.26 - 1.16
Colstrip	0.8 - 1.2	0.98 - 1.72
Beulah	0.7 - 0.9	1.12 - 1.49

If the coal must be desulfurized anyway, one may question the validity of shipping this coal to regions which have local suppliers which, on a Btu adjusted sulfur basis, are not much more polluting or which could be desulfurized. The saving in transport costs by any mode, due to shorter distance, could be applied to desulfurization.

It must be emphasized that, with respect to unit train-coal slurry pipeline comparisons, a worst case comparison has been developed. Unit train costs are too high; slurry pipeline costs, even though they have been inflated, are based on

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Black Mesa data, which pertain to a much smaller line, and on ETSI-Bechtel preliminary engineering estimates for a line in which they have a vested interest. The value of coal inventories and pipeline holdup have also been kept arbitrarily low. On the other hand, all railroad right of way upgrading, even though this benefits all freight movement, has been assigned to unit coal train costs. No credits are taken for the movement of other freight, which is impossible with respect to the pipeline, a major factor favoring the railroads. Furthermore, emphasis has been placed on an artibrarily low bottleneck speed of 10 mph over various percentages of the route. Had the bottleneck speed been higher, say 20 mph, all of the comparative unit train cost functions would have shifted downward. This must be kept firmly in mind when reading the discussion or examining the figures in this Section.

5.2 Slurry Pipeline and Unit Trains.

Over all the routes under consideration, the slurry pipeline, without water return, is competitive with unit trains if the railroad has bottlenecks of a 10 mph speed limit to the equivalent of 10 percent of the distance. In addition, there is usually a greater railroad distance between points. The best pipeline case can be made for the Colstrip, Montana to Seattle, Washington route, where the terrain may yield a bottleneck of more than 20 percent of the distance at 10 mph speed limit. There, the return of the water after slurry dewatering may become feasible if the return pipe and pumping equipment costs an average of only $240,000 per mile; although a more conservative estimate is $480,000 per mile. When a slurry pipeline is built especially for exporting coal, the higher price of $400,000 per mile might be justified because the coal is readily loaded into ships designed for carrying bulk material and there is a convenience factor involved in unloading at the destination.

The slurry pipeline can be written off on the basis of a 25- or 30-year take or pay sales contract for the coal from a given mine are. For example, at 25 MMTY and $12 per ton as mined, annual costs ($ million) are:

	Slurry Pipeline	Unit Train
Coal (dry basis)	300	315
Shipping	208	185
Pulverizing		5
Total	508	505

This is because rail shipped coal may have on the average of about 5 percent moisture even with wind drying after mining. The above differential is within the accuracy of our estimates. A higher cost of the slurry pipeline might be expected if environmental factors work against export shipments.

The value added by delivering coal in pulverized form is not a major factor in a decision among modes of transport. One reason is that beneficiation of coal by removing ash via washing is usually done at a size range above 1x0" prior to pulverizing. This is readily done for both unit train and slurry pipeline shipment. This was not done at the Black Mesa where the coal, as mined, has a heating value of up to 13,000 Btu/lb. A second reason is that dewatering produces slurry cakes which must be repulverized in, for example, Raymond bowl mills before feeding into the boiler furnace. Depending on the grindability of the coal, pulverizing the coal after shipment by unit trains may mean an additional cost of $0.10 to $0.20 per ton.

After mechanical drying the coal slurry retains 25 percent moisture in the coal cake. This means an average decrease of 250 Btu/lb. in the heating value for coals of about 10,000 Btu/lb. Hence, the loss is not serious. Drying by heating is certainly not justifiable. An increase of the air preheating temperature can be accomplished in any case via a suitable air preheater. Moreover, some coal, as mined, may contain up to 30 percent moisture.

The unit costs are given in Sections II and III respectively, for unit trains and slurry pipelines. Comparisons of their operation at various capacities are given in Fig. 5.1(a)(b)(c) for a range of normal design flexibility. Figure 5.1(b) shows a comparison of a slurry pipeline designed for a 5 mph flow with unit trains on the Gillette to Chicago route.

Unit train costs might be adjusted according to the moisture content of the coal shipped; the slurry pipeline mix should include the moisture content of the coal used in forming the slurry at the design condition.

Analysis leads to our previous conclusion that a slurry pipeline is definitely superior where a railroad is not available. However, even if 15 percent new road is to be built and operation includes a 10 percent bottleneck at a 10 mph speed limit and a mileage saving less than 30 percent, the unit train is still likely to be the cost effective choice.

5.3 Comparative Studies.

Several recent studies by other investigators are produced in Appendices to this Section. Not all have been explicitly analyzed here.

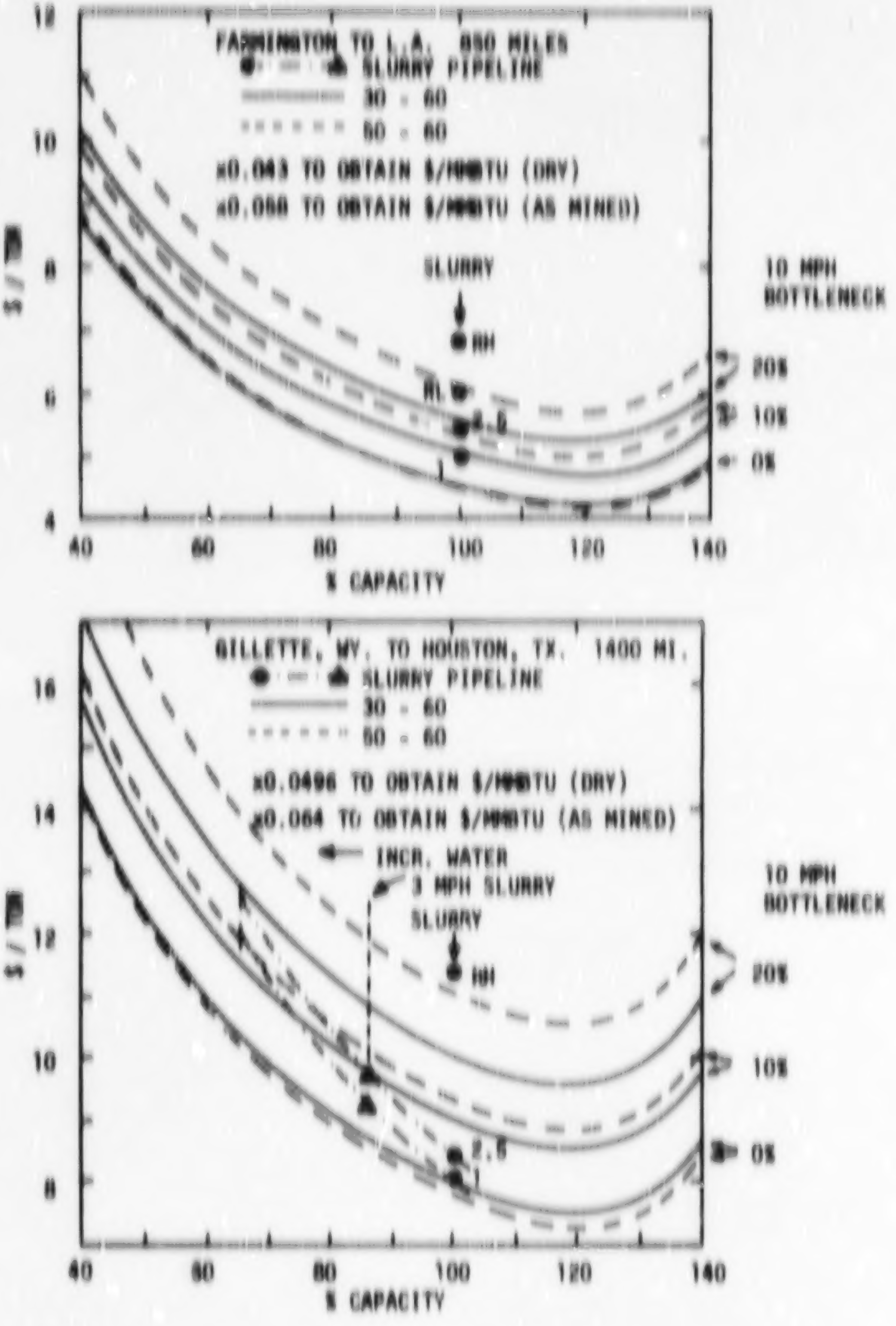

FIGURE 5.1(a) UNIT COSTS AT VARIOUS CAPACITIES - UNIT TRAIN & SLURRY PIPELINES

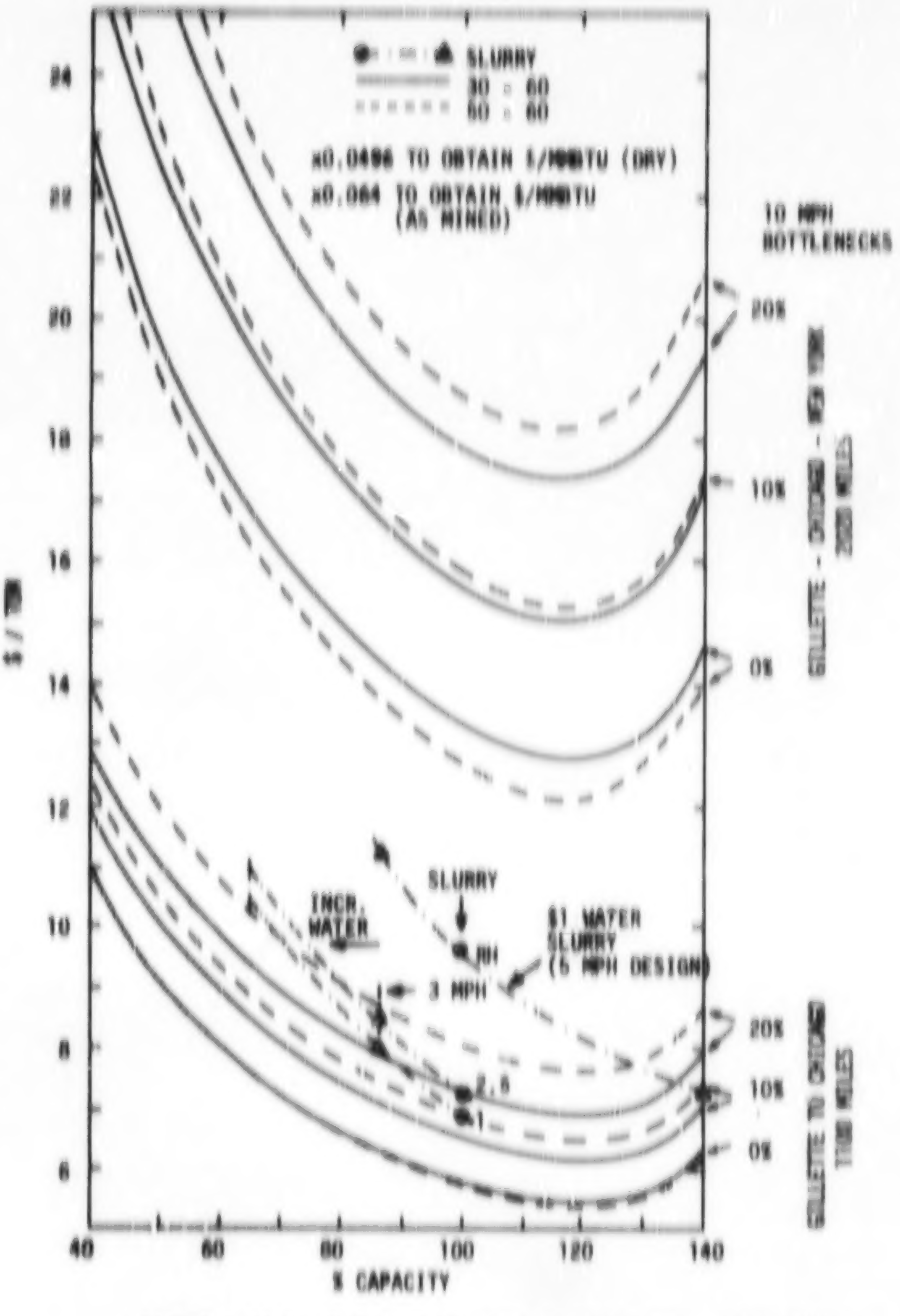

FIGURE 5.1(b) UNIT COST AT VARIOUS CAPACITIES - UNIT TRAINS

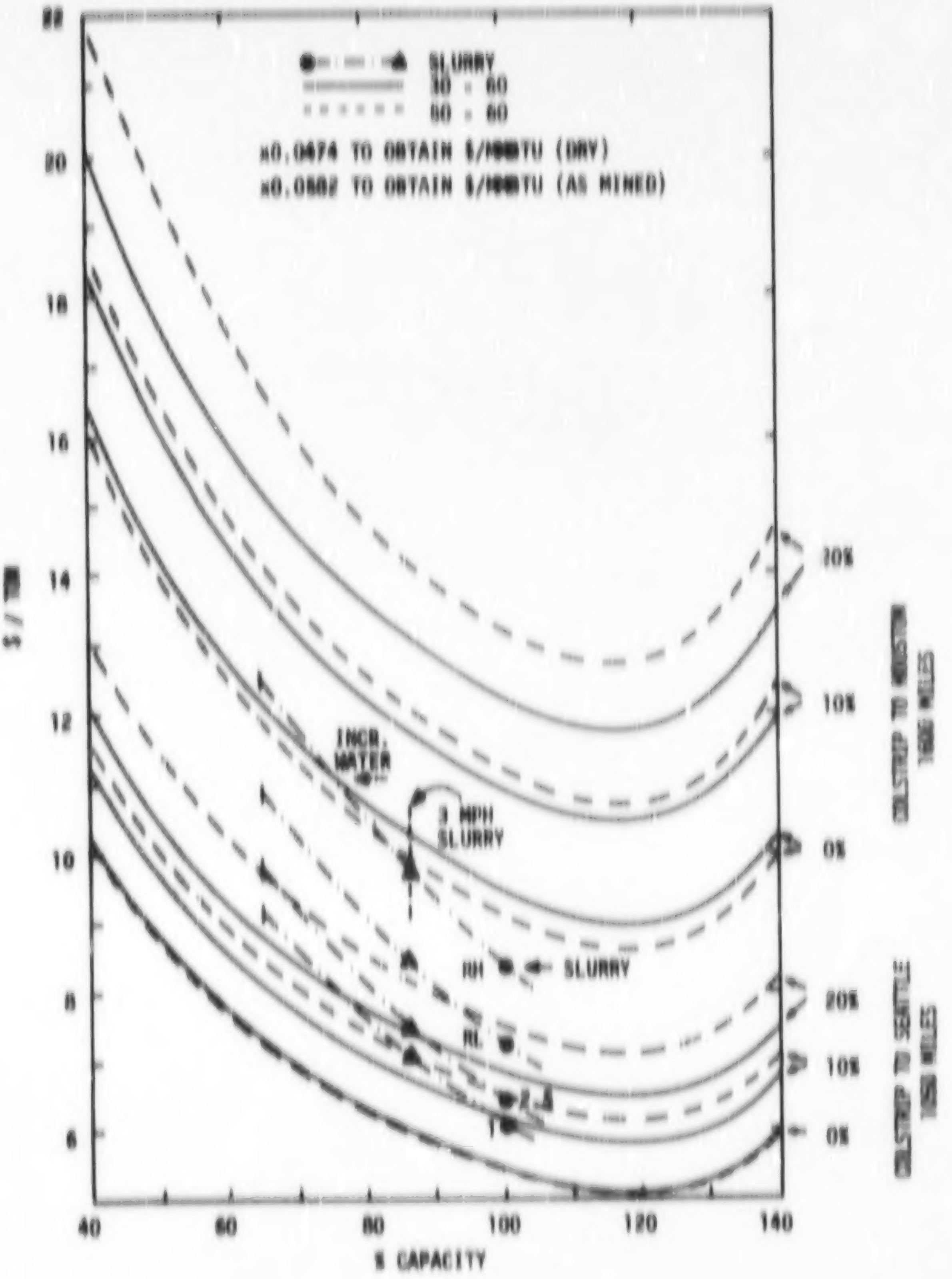

FIGURE 5.1(c) UNIT COSTS AT VARIOUS CAPACITIES - UNIT TRAINS AND SLURRY PIPELINE

APPENDIX A TO SECTION V

COMPARATIVE DATA - COAL SLURRY PIPELINES AND UNIT TRAINS: BECHTEL AND STANFORD RESEARCH INSTITUTE

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APPENDIX A TO SECTION V

COMPARATIVE DATA: COAL SLURRY PIPELINES AND UNIT TRAINS - BECHTEL AND STANFORD RESEARCH INSTITUTE

The most recent of these data sources is a study by the Bechtel Corporation (a 40 percent owner of ETSI), Clean Coal Energy: Source-to-Use Economics, Final Report (Draft) to ERDA, Contract No. E(49-18)-1552, January 1976.

Coal transport prices (not costs) were based on conventional rail rates estimated from the 1972 Carload Waybill Statistics (a sample) published by the Federal Railroad Administration [2-33]. A national average rate equation (rather than a route specific analysis) was used for all conventional rail shipments of coal [2-36]. The estimating equation used was $C = PD^{-Q}$ where C is the conventional rail rate in mills/ton/mile, D is the rail distance, and P,Q are hyperbolic parameters. The extent of the differences (price not cost based) can be seen in the range between western and southwestern routes, respectively: $C = 42.7D^{-0.242}$, and $C = 394.3D^{-0.543}$. The average U.S. rate was $C = 179.5D^{-0.446}$ [2-34].

For unit train prices (again not costs) a nominal train of 100 cars carrying 10,000 tons was assumed. Price estimates (1974 dollars) for western railroads were estimated for one way distances of 100-1500 miles. These ranged from 20 to 7 mills/ton/mile, respectively. For 1000 miles, the rate was estimated at 8 mills/ton/mile [2-37 and 40]. Existing ICC rates were reported to range between 4 and 13 mills/ton/mile at 1973 prices [2-39]. The trend equation used by Bechtel to generate average western 1974 prices was $C = 122.45D^{-0.391}$. They note, however, that real prices are tailored by each move-

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ment and vary depending on degree of competition, annual tonnage, train and car size, type of car, loading and unloading method, terrain, and track conditions.

To forecast both conventional and unit train prices, they extrapolate the historical index of railroad material and wage rate for use as the base case [2-40]. This blurs the difference between unit train movements and those of all other freight. Unit trains do not use the same component values and have had the benefit of some technological improvements. Based on the general historic data, Bechtel uses an inflation rate of 7.5 percent in current dollars or 2.5 percent in constant dollars. Between 1967 and 1973 (the end of their series, they note that the combined index for material and labor for all rails and for all types of shipment (neither costs, nor route specific, nor by commodity, nor by unit train) rose from an index of 100 to 163.5, and at an accelerated rate. Between 1973 and 1985 they appear to rely on a generalized (again the caveats should be noted) model indicating an average annual increase in material costs of 5.8 percent and labor costs of 8.3 percent [2-41].

Based on a unit train of 100 cars (capacity 10,000 tons/train), a total of 8-10 hours for loading and unloading, and (for our purposes most important) an average train speed of 20-25 mph, Bechtel estimates the number of trains per day on a double track route at 60 for unsignalled routes, 120 for automatic block routes and 160 for routes with centralized traffic control. If the routes are single tracked, these fall to 20-40-60 trains, respectively [2-42].

For slurry pipelines, Bechtel shifts to an analysis based on costs (not prices) which includes under capital costs only preparation, line storage, dewatering and transport. Water supply and water cleaning facilities are excluded [2-57]. The analysis is subdivided into fixed (capacity dependent) and variable costs (capacity and length dependent)[2-57]. Hypothesized cost inflation for both is dependent on the gross national product implicit price deflator index (which is comparable to the 2.5 percent constant dollar index noted above for rails rather than the 7.5 percent escalation factor)[2-58]. They claim that elevation differences, terrain, and soil conditions affect costs by less than ±10 percent, while economic factors such as interest on debt and the amortization period also affect costs by less than ±16 percent [2-58 and 59]. Load factors are claimed to have a substantial effect on fixed and a negligible effect on variable costs but all estimates were made assuming a 100 percent load factor [2-59].

Their general conclusion, based on the above, is that in 1974 dollars, for slurry pipelines carrying $5x10^6$TPY, costs are consistently above unit train prices (not costs) on a mills/ton/mile basis, but the unit train tonnage basis is not specified. At $10x10^6$TPY, slurry pipeline costs are below unit train prices except for distances of less than about 100 miles or more than about 1200 miles. At $20x10^6$TPY, slurry pipeline costs are shown to be significantly below (about 0.2 cents/ton/mile at 1000 miles) unit train prices over the entire range of distance [2-60]. A mixed cost-price comparison is untenable. The other anomalies have been noted above.

Bechtel suggests that their analysis should be interfaced with their model, developed for NSF, and called the NSF/Bechtel Energy Supply Planning Model for manpower, materials and capital requirements [7-17]. The original data for unit trains and slurry pipelines was developed and prepared for Bechtel (in support of Contract NSF-C-87) by the Stanford Research Institute, Manpower, Materials, Equipment, and Utilities Required to Operate and Maintain Energy Facilities, March 1975. These estimates are appended. In particular, it should be noted that the estimates for slurry pipelines are heavily dependent on the Black Mesa line [references 1 and 4 page 247], Bechtel [reference 3 page 247], and ETSI/Bechtel [reference 5 page 247]. With respect to unit trains, the differences in the assumptions [p.237] should be explicitly noted, in particular distance, trip time, shipment size and an eastern rather than a western route. All of these imply high cost. Again, prices (tariffs) are used for rails [p.242] but costs are used for the slurry pipeline [p.249] for the final comparison.

The draft final report of the NSF/Bechtel study, The Energy Supply Planning Model, July 1975, specifies the use of nominal facilities (SRI) and average haul length. These, however, are the basis for the interregional transport analysis [4-22 and 23] except that,

> "The use of certain modes between O-D pairs (origin-destination) must be explicitly specified by the user because of the rarity of use of the mode (e.g., 400kVDC electric transmission lines and coal slurry pipelines. In these cases, the user must specify the percentage of flow between O-D pairs to be transported by these modes. The remainder of the flow is handled by one of the other algorithms...." [4-24].

In short, slurry pipelines have a unique position in this study, [see also 4-28]. The NSF/Bechtel limitations regarding rail analyses are documented and their results are deemed only indicative [4-35]. Nevertheless, it is stated that,

> "...the Interregional Transportation Facilities Generator converts regional fuel flow networks

> to transportation facility requirements, based on a great deal of transportation system data (haul lengths, regional shares, carrying capacities, etc.) and user-specified (or default) regional transportation modal-split coefficients. The modal-split coefficients specify the fractions of a particular fuel's incremental flow (positive or negative) over a particular origin-destination combination that is to be assigned to the various competing transportation modes" [5-25].

Thus, the analyses, and problems in the SRI-Bechtel analyses, cited above, as well as the asymetric inclusion of the slurry pipeline engenders problems in the conclusions. If the user tries the default coefficients, he may not even know of the biases.

The NSF/Bechtel estimated facility data comparisons [Table G-3], upon which their conclusions are based, include the following: (1) Coal train at 10,500 short ton capacity have capital costs of $4.6 million. (2) The coal slurry pipeline at 70,000 short tons per day has capital costs of $412 million with preparation and dewatering capital costs of $138 million at a capacity of 68,600 short tons per day. The approximate accuracy range is given in the following table:

	Detailed Data	Major Subtotals	Total Capital Cost
Coal Train	--%	--%	±10%
Coal Slurry Pipeline	±25	±20	±10
Slurry Prep. and Dewater.	±25	±20	±10

It is stated [Table G-5] that the coal train estimates are accurate and compare to ICC and USBM reports (a price basis) while the coal slurry pipeline estimates are accurate and are compared to a shorter (Black Mesa) slurry line (costs).

The inclusion of the slurry pipeline in the NSF/Bechtel study is not obvious. It is not mentioned in either Section 7 or 8 of the document where the President's 1975 energy statement and the possible scenarios are discussed. It may be found in the Appendix H printout (H-51), schedule of selected major materials and equipment required for construction of all transportation facilities required to supply fuel mix as required in the President's 1975 State of the Union Message, for region 6, the west north central area (Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota and South Dakota). There it will be observed that the number of compressors and drives of over 1000 hp are zero from 1974-1976, three in 1977, thirteen in 1978, ten in 1979, and zero again from 1980 through 1985.

If coal transportation costs are misstated or misunderstood, not only may coal be mined in the wrong location, it may move by the wrong mode.

Material Omitted

For comparative data see: Stanford Research Institute, *Manpower, Materials, Equipment, and Utilities Required to Operate and Maintain Energy Facilities*, March 1975, pages 247-249.

APPENDIX B TO SECTION V

COMPARATIVE DATA
EBASCO AND BECHTEL

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APPENDIX B TO SECTION V

A. J. BANKS, "ENERGY TRANSPORTATION," PRESENTED AT THE EBASCO CONFERENCE PHOENIX, ARIZONA, OCTOBER 1975

For comparison with EHV transmission and slurry pipeline costs, this study explicitly counterpoises unit train prices (tariffs). Therefore, this review will concentrate on the first two modes.

1. Electric Transmission, 765 kv AC and ±600 kv DC.

Bundled conductor configurations, single circuit construction, double line, and series and shunt compensation are assumed for AC transmission. The cost figures include the increase in investment and fuel costs, where needed, to account for I^2R losses.

Specific assumptions include:

(1) To levelize annual cost figures, a 10.9 percent discount rate was used.

(2) Amortization is over a 30 year period.

(3) Annual escalation equals 6 percent.

(4) American utility experience provided the basis for 765 kv AC costing.

(5) The 600 kv DC line, using a bundle of four 954 kcmil conductors was estimated at 75 percent of the cost of similar 765 kv AC lines.

(6) DC line voltage and conductor configurations were extrapolated from (5) by Peterson's formula.

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(7) DC terminal costs are based on manufacturers' information with an allowance for ground electrodes.

(8) Right of way permits a collapsing tower and is estimated at $2,500/acre, including clearing, access, etc.

(9) Fixed charges equal 16 percent of depreciable items and 20 percent of non-depreciables. Financing was at utilities' debt/equity ratio.

(10) Investment costs for 1980 operation escalated at 7.5 percent/year. O and M costs are one percent of investment costs.

(11) The approximate percent range of annual costs subject to escalation is 24.0-54.3. The variation is due to I^2R losses which vary with load and distance.

For a sample ±600 kv DC two circuit line transmitting 3,200 MW, investment costs ($ 000) are approximately:

Right of way at $2,500/acre	$131,000
Power line terminals	380,000
Power line	534,000
Total	$1,045,000

The results, for comparable facilities described in our study are shown in the following table.

TRANSMISSION LINE TRANSPORTATION COSTS, TWO CIRCUITS* 1980 INITIAL OPERATION 3,200 MW DELIVERED LOAD

Optimum Voltage	Distance (miles)	Line Loss (MW)	Investment ($ 000)	Levelized Annual Cost ($ 000)
765 AC	500	130	618,000	155,710
±600 DC	900	187	1,045,000	252,400
±600 DC	1500	312	1,516,000	376,390

* ±600 kv DC Conductor bundles 4-954 kcmil.
765 kv AC Conductor bundles 4-954 kcmil.

ANNUAL LEVELIZED UTILITY OWNING AND OPERATING COSTS
($ 000)

Distance (miles)	500	900	1500
Capacity (MW)	3200	3200	3200
	765 kv AC	±600 kv DC	±600 kv DC
Fixed Charges	101,940	172,510	251,720
Operating	53,770	79,890	124,570
Total	155,710	252,400	376,390

2. Coal Slurry Pipelines.

The general configuration assumed for this mode includes a 50-50 coal-water slurry, pipeline pressure 1200 psi which on level terrain drops to 100 psi at 70 miles, 70 mile pumping station spacing each with dump ponds capable of accomodating the upstream segment, a velocity of 4.09 mph, and water treatment after removal to eliminate fine dust, the water to be used for in-plant services. The pipe size for the movement of 25 MMTY is 40". Water evaluation is not undertaken.

Specific assumptions include:

(1) EBASCO estimation of costs.

(2) Fixed charges based on 80/20 percent debt/ equity financing are 14 percent.

(3) Energy costs at utility rates.

(4) Material costs escalated at 6 percent/year and labor costs at 8 percent/year to obtain 1980 costs.

(5) The approximate percent of annual costs subject to escalation equals 27.1.

A sample 900 mile pipeline delivering 9 MMTY for 1980 operation is estimated at ($ 000):

Coal slurry preparation plant	$ 92,000
Coal pipeline	348,000
Pumping stations (12)	155,000
Dewatering plant	115,000
Total	$710,000

The results, for comparable facilities described in our study are shown in the following table.

PIPELINE TRANSPORTATION COSTS, 1985 OPERATION,
25 MMPY DELIVERY

Distance (miles)	Pipe Diameter (inches)	Investment ($ 000)	Levelized Annual Cost ($ 000)
900	40	2,090,000	401,530
1500	40	2,660,000	511,030

ANNUAL LEVELIZED OWNING AND OPERATING COSTS
($ 000)

Distance (miles)	900	1500
Fixed Charges	292,600	372,400
Operating	108,926	138,633
Total	401,526	511,033

P. J. NAGARVALA, G. C. FERRELL AND L. A. OLVER,
CLEAN COAL ENERGY: SOURCE-TO-USE ECONOMICS,
VOL. 1, MODEL, DATA AND RESULTS
DRAFT, JANUARY 1976, THE BECHTEL
CORPORATION FOR USERDA
CONTRACT NO. E(49-18)-1552

Bechtel's sketch of the slurry pipeline basis is presented from their report along with their slurry-unit train comparisons.

This material has been omitted. See pages 2-57, 2-58, 2-59, and 2-60 of the cited report.